A Limnological Reconnaissance of Selected Eagle Cap Wilderness Lakes and Paleolimnological Assessment of Mirror Lake

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EXECUTIVE SUMMARY

This report describes the results of a study conducted on selected lakes in fall 1998 in the Eagle Cap Wilderness, located in the Wallowa-Whitman National Forest of northeastern Oregon. The purposes of the study were (1) to characterize the acid-base chemistry of 15 lakes in the wilderness, (2) describe baseline limnological properties of these lakes, and (3) to reconstruct the paleolimnology of a prominent recreation site, Mirror Lake.

The results show that the study lakes are insensitive to chronic acidification associated with acidic deposition. The primary measure of lake capacity to neutralize acidic inputs, acid neutralizing capacity (ANC, also referred to as alkalinity), ranged from 59 to 196 µeq/L. pH values of the lakes ranged from 6.6 to 7.1. Studies of lakes that acidified in the northeastern United States generally had pre-industrial ANC values less than 25 µeq/L. Furthermore, the nature of the dominant chemical weathering in the study area (congruent dissolution of carbonates) indicates that natural weathering reactions could compensate for any realistic increases in acidic deposition. This study conducted during the fall did not address the risk of episodic acidification associated with acid anions accumulated in snowmelt runoff. The current risk of both chronic and episodic acidification for these lakes is probably low given available information regarding regional emissions of N and S.

The median transparency of the study lakes was relatively high (~ 10 m for lakes deeper than 10 m) typical of unproductive alpine and subalpine lakes. Total phosphorus concentrations were moderately high with a median value of 10 µg/L. Inorganic nitrogen concentrations were low, indicating that the lakes appear to be N-limited systems, a common feature in the West.

Efforts to maintain these and related lakes in their present condition should focus on minimizing anthropogenic sources of nitrogen to these watersheds. The phytoplankton populations were highly diverse among the study lakes with respect to species richness, community composition, and abundance. Phytoplankton species richness in the study lakes ranged from 4 to 25. Dominant taxa varied widely among the lakes and included most major classes and divisions of algae. Phytoplankton biovolume varied by a factor of six among the lakes. Phytoplankton biovolume was poorly correlated with total phosphorus providing further support for characterizing these lakes as N-limited for at least part of the year.

The paleolimnology data generally show that only minor qualitative changes have occurred in Mirror Lake over the last 2000 years. The diatom and sediment chemistry show evidence of

three recognizable stages, the most recent occurring in the last 60 years. The charcoal record in the sediment indicates a fairly stable input of fine material, probably defined from moderate to long-range transport of combustion products. The two methods of dating the lake sediments indicate that a major change in sediment accumulation rate may have occurred during the 19th century. The ^{14}C dating of two intervals shows a low rate of sediment accumulation in the lower sediments (below 15 cm). The upper sediments, dated using ^{210}Pb, show a much more rapid rate of sediment accumulation. The sediment accumulation rate in the upper 6 cm is lower than the rate at the turn of the century, suggesting that a high rate of accumulation occurred in the last century and the present rate of accumulation is approaching the long-term historical rate. One possible explanation for the lack of concordance in the sediment dating is that early use of the area for grazing may have caused an increase in erosion, although there are no independent data presently available to confirm this hypothesis.

I. INTRODUCTION

The Eagle Cap Wilderness in the Wallowa Mountains of northeastern Oregon encompasses some of the most stunning scenery in the Pacific Northwest. The jagged ridges radiate out from the core of the wilderness, forming an interlacing weave of sharp ridgelines and deep glaciated valleys. The glacial retreat that created the striking landscape left behind a number of small lakes which serves as a recreational resource for the area. Although the Eagle Cap Wilderness is insulated from land use activities that threaten lakes outside the wilderness, no area is immune to degradation of airsheds. Acidic deposition in parts of North America and northern Europe have caused extensive damage to aquatic resources in areas little affected by watershed activities.

Relatively little data are available to characterize the lakes in the Eagle Cap Wilderness. Thus, there was little basis to on which assess their baseline status and virtually no information available to determine if they had been altered either by recreational use in the watersheds or inputs from atmospheric deposition. The purpose of this project was to collect limnological information on a group of these lakes, assess their current status, and determine if they may have been altered to any measurable degree. Regardless of their status with respect to possible change, the data collected in this reconnaissance would form a basis for evaluating change for future conditions.

II. STUDY LAKES

The focus of the study was to characterize the sensitivity of lakes in the Eagle Cap Wilderness to damage from atmospheric inputs and to assess detailed evidence for historical change in one lake. Constraints in budget and time available for sampling with the threat of inclement weather limited the sampling to lakes largely within and near the Lakes Basin in the center of the wilderness. The locations of the 15 lakes selected for sampling are shown in Figure 1 and listed in Table 1. Mirror Lake was selected from this list for paleolimnological study to evaluate historical changes in the lake determined by analysis of the lake sediments. The study lakes are generally small natural lakes created during the recession of the last glaciation. An exception is Minam Lake, which was created by impounding the Lostine River.

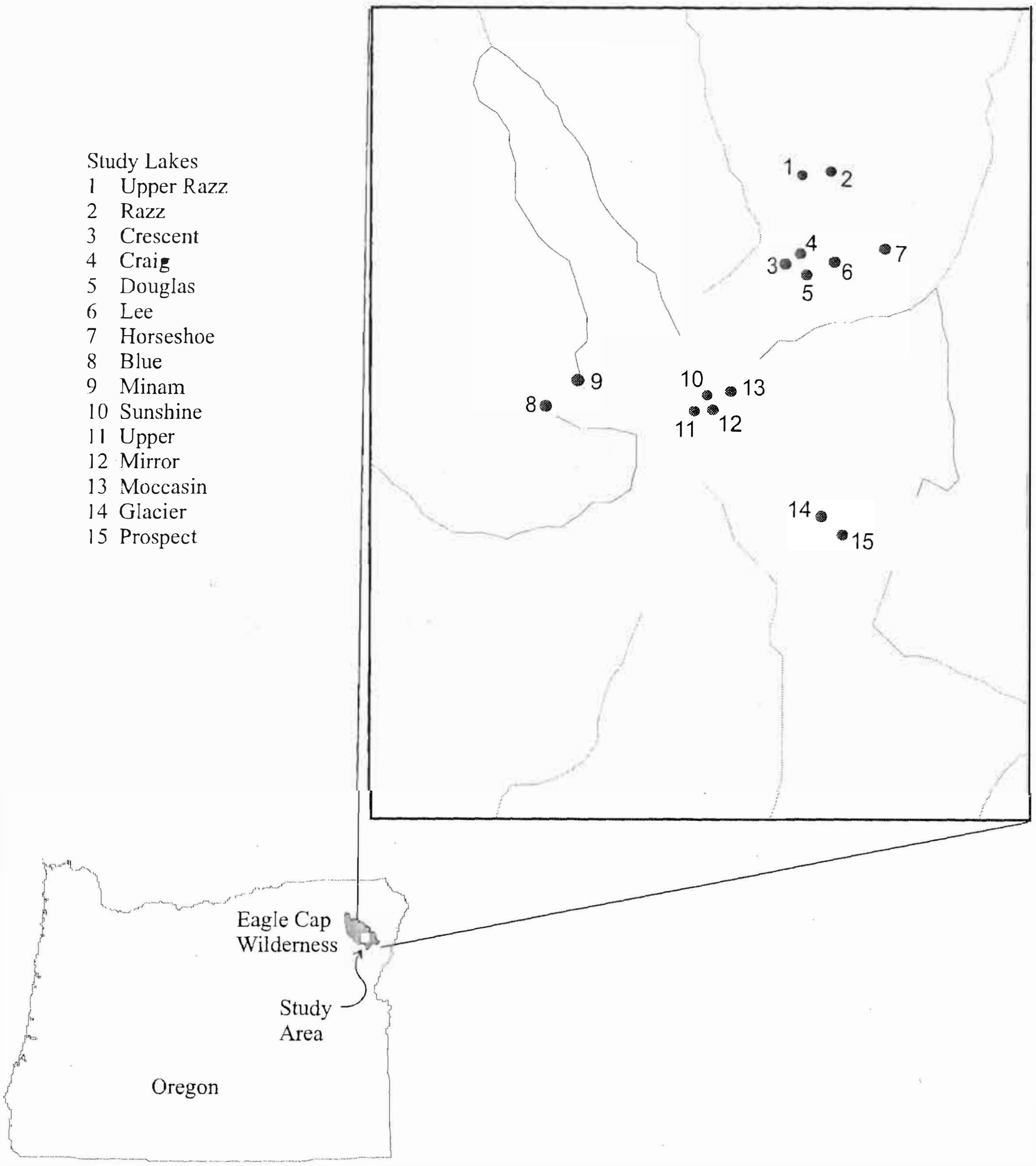

Figure 1. Study area, Eagle Cap Wilderness.

Table 1. List of study lakes in the Eagle Cap Wilderness.

Lake	Sample ID	Duplicates
Blue	BLU	
Minam	MIN	
Upper	UPP	
Mirror	MIR	
Sunshine	SUN	Yes
Moccasin	MOC	Yes
Crescent	CRE	
Craig	CRA	
Douglas	DOU	
Lee	LEE	
Horseshoe	HOR	
Razz	RAZ	
Upper Razz	BEN	
Glacier	GLA	
Prospect	PRO	

III. METHODS

The intent of this investigation was to gather as much descriptive limnological information on as many lakes as feasible, while balancing the need for detailed information on status and trends. The design we selected consisted of sampling 15 lakes from which water and phytoplankton samples were collected. One of these, Mirror Lake, was selected for detailed paleolimnological reconstruction to assess the evidence for recent change. The study lakes were located in a pattern radiating from Mirror Lake in the Lake Basin (Figure 1). This allowed the lakes to be sampled efficiently, yet provided samples from lakes in several different watersheds.

Surface water samples were collected from near the center of each lake, except for Minam, Blue, and Upper, which were near-shore samples. Aliquots for total phosphorus and phytoplankton were preserved in the field using sulfuric acid and Lugol's solution, respectively.

Aliquots for major ions were kept cold and unpreserved for transport to the laboratory. The major ion aliquot was stored in a 0.5 L Nalgene® container. Samples for major ion chemistry were shipped to the USDA Forest and Range Experiment Station in Fort Collins, CO via overnight courier in coolers. Samples for total phosphorus and phytoplankton were shipped to Aquatic Analysts in Portland, OR.

Four sediment cores were collected from Mirror Lake using a mini-Glew gravity corer equipped with 2.5 cm diameter core tubes. Cores 1, 2, and 3 were section on-site in 1 cm increments. Core 4 was retained intact and saved as a "backup." The sectioned sediments were shipped to the University of Toronto for inspection and sample processing. The sediments were analyzed for water content, loss-on-ignition (LOI), diatom community composition, and charcoal. The sediment dating was measured using ^{210}Pb and ^{14}C. Age of recent sediments was computed using the constant rate of supply (CRS) model.

A. Radiometric Dating

Sediment Core A was prepared for radiometric dating, and the results were assumed to reflect the age profile of Core C as well. Sediment intervals 0-1 cm through 9-10 cm, 14-15 cm and 19-20 cm were dried in uncovered crucibles for 24 hours at 100 °C. The dried sediment was then ground into a very fine powder with a mortar and pestle. The powdered sediment was placed into plastic 50 mL centrifuge tubes, and the weight of the sediment determined. These tubes were sent to *MyCore Scientific Inc.* to be dated by Pb-210. Sediment intervals 18-19 cm and 28-29 cm were sent to *Beta Analytic, Inc.* to be dated by AMS C-14. The results of these dating analyses can be found in Appendices 1A and 1B.

B. Diatoms

1. Preparation

A small amount (an average of 0.2 g) of each sediment interval for Core A was transferred into a glass scintillation vial. Samples were digested with a 1:1 mix of HNO_3/H_2SO_4. Each sample was washed with distilled water eight times. Four sequential dilutions of 50% were made from the original digested slurry for each sediment interval. These were labeled A, B, C and D, where D was the most dilute.

2. Microscopy and Taxonomy

Each dilution was plated on a cover slip and subsequently mounted on a microscope slide using Naprax® mounting medium (R.I.=1.74). Diatom taxa were photographed at *ca.* 1000X magnification using one of two setups: 1) a Nikon FDX-35 camera with Tech Pan film exposed at 50 ASA mounted on a Nikon Optiphot-2 microscope 2) an RS-Photometrics CoolSnap digital camera mounted on Leica DMRB microscope. Identification of the taxa was made primarily using the following references: Krammer and Lange-Bertalot 1986-1991 and 1997; Lange-Bertalot and Krammer 1989; Cumming et al. 1995; Germain 1981.

The most dilute mount (D) for each interval was generally what was examined under the microscope for the counting step. The first count of the 0-1 cm interval was made to a total of ~500 valves. Subsequently, the relative abundance and composition of the assemblage remained consistent beyond the count of ~300 valves. Thus, all subsequent counts were taken to a total of ~400 valves. Taxonomy was further refined, and the final species list consisted of only those taxa that were present in a relative abundance of at least 1% at one depth interval. The stratigraphy of this data set was plotted using TILIA (Grimm, 1991, 1992).

3. Statistical Methodology

Ordination is a term that is used to collectively refer to multivariate techniques that organize sites along axes based on species composition data (Jongman et al. 1987). The goal of an ordination analysis is to arrange point such that those close together correspond to sites that are similar in species composition, and points that are far apart indicate sites that are dissimilar in species composition (Jongman et al. 1987).

Detrended Correspondence Analysis (DCA) is an unconstrained analysis. The site scores (in this case, the depth intervals of the core) are calculated via weighted averaging which results in a standardization of the data where the within-site variance equals 1 (Jongman et al. 1987). The purpose of detrending is to ensure that the mean value of the site scores on the subsequent axes is around 0 at any point along the first axis (Jongman et al. 1987). This is an attempt to overcome the arch effect often observed in correspondence analyses. With DCA, species points located towards the margins of the 2-D plot are often rare species typical of extreme environmental conditions (Jongman et al. 1987). As a result of standardization, the contribution of rare species to the results of the analysis is greater than their relative abundance.

Principal Components Analysis (PCA) is also an unconstrained analysis. PCA constructs a theoretical variable that minimizes the total residual sum of squares after fitting straight lines to the species data (Jongman et al. 1987). This is accomplished by the ordination technique choosing the best values for the sites; the site scores (Jongman et al. 1987). This ordination method relates to a linear response model based on the assumption that the abundance of any species either increases or decreases with the value of each of the latent environmental variables (Jongman et al. 1987).

The axes of the PCA ordination are constructed by a least-squares regression, which weights all species equally (Pielou 1984). As a result, the more abundant species tend to be emphasized in the construction of the axis gradient since they tend to have higher variances than rarer species (Pielou 1984). This method works well if the data swarm is linear, but may be distorted if the swarm is non-linear (Pielou 1984).

Eigenvalues are an integral part of the interpretation of ordination analyses. Eigenvalues are values that reflect the relative contribution of individual components to the explanation of the total variance in the data (Kent and Coker 1992). The magnitude of the eigenvalue for a component indicates the importance of that component in explaining the total variance within the data set (Kent and Coker 1992). Eigenvalues in DCA represent the (maximized) separation of the species scores on the ordination axis (Pielou 1984). Therefore, in order to determine the percent of variance contributed by each axis in DCA, the eigenvalue must first be divided by the total inertia, then multiplied by 100. In PCA, eigenvalues are direct reflections of the percent of variance explained by each of the axes. They represent a portion of the total sum of squares in the species data extracted by the axis of ordination. To obtain the percent of variance, the eigenvalue is simply multiplied by 100.

Using CANOCO (ter Braak 1998), a DCA was performed on the diatom relative abundance data obtained from the analysis of the Mirror Lake core. The data was detrended by segments in order to obtain estimates of gradient lengths in standard deviation units of species turnover (SD) (ter Braak et al. 1998). Axis 1 of a DCA is the axis of greatest change. A gradient length greater than 4 SD is indicative of a strong unimodal response (ter Braak et al. 1998).
Since the data exhibit a linear response, a PCA ordination was performed on the data, again using CANOCO for Windows (ter Braak 1998). Scaling was focused on inter-species correlations rather than inter-sample distances in order to clearly see the species distribution among the samples. The only difference between these two options is that the ranges of the

samples and species scores on one ordination axis with respect to the other are either expanded (as in this case) or diminished (ter Braak et al. 1998); the overall distribution remains the same. Species scores were divided by standard deviation in order to prevent the species with the largest variance from dominating the ordination diagram (ter Braak et al. 1998). Similarly, since species with extreme variance may have a disproportionately large influence in the ordination, the species data was put through a square-root transformation (ter Braak et al. 1998). Samples were neither standardized nor centered, since inter-species correlations were being examined. Species were centered by species, since in an ordinary PCA based on a covariance matrix, each species is implicitly weighted by its variance (ter Braak et al. 1998).

4. Reconstruction

Of the 55 abundant (at least 1% relative abundance) taxa in Mirror Lake, 17 of those were also present either individually or lumped within the species of the Cascades calibration set (Eilers et al. 1998); two taxa that were marked '*cf.*' were not lumped with their counterparts, and were thus not considered in the reconstruction analysis. The taxa in common between the two data sets were: *Achnanthes levanderi*, *Achnanthes minutissima, Achnanthes subatomoides*, *Achnanthes suchlandtii*, *Asterionella formosa*, *Aulacoseira distans, Cyclotella pseudostelligera*, *Cyclotella stelligera*, *Cymbella minuta*, *Fragilaria brevistriata, Fragilaria capucina var. rumpens*, *Fragilaria construens var. venter*, *Fragilaria pinnata*, *Navicula cryptocephala*, *Navicula cryptotenella*, *Navicula laevissima*, *Navicula pupula*. ANALOG (Schweitzer 1996) was run with these taxa as the fossil data and the Cascades calibration (Eilers et al. 1998) taxa as the modern data in order to quantify the overlap between the fossil and modern data sets.

WACALIB Version 3.2 (Line et al. 1994) was run in order to reconstruct the environmental changes downcore based on the optima of the species in common with the Cascades calibration set (Eilers et al. 1998). Bootstrapping and classical deshrinking were performed as part of this analysis by WACALIB. Deshrinking minimizes the root mean square error (RMSE) in the data set being analyzed (Birks et al. 1990). Bootstrapping is a resampling procedure that mimics sampling variation in the data set being analyzed (Birks et al. 1990). It is used to derive the RMSE of prediction for individual reconstructions (Birks et al. 1990).

Reconstructions were performed on the following environmental parameters (all of which were log transformed in the calibration analysis except pH): area, depth (maximum), conductivity, pH, SO_4, Cl, alkalinity, total phosphorus (TP), Na, K, Ca, Mg. However, from the

correlation matrix (Eilers et al. 1998, 43) conductivity is highly correlated with the ions present, thus the individual ionic parameters were not subsequently considered in this analysis. Area and depth were also omitted from further analysis, since the accuracy of those reconstructions would be highly questionable. In addition, alkalinity was discarded, as these values are not very useful (Sweets, pers. comm.). Thus, only pH, TP, and conductivity were considered for further analysis. It should be noted that all reconstructions were performed using Calset B, which eliminates lakes 29, 30, 33, 40, 45, 46 and 47 from the analysis (Eilers et al. 1998).

In addition, a ratio of planktonic vs. benthic diatoms was calculated for Mirror Lake, Core A. All the centric taxa as well as *Asterionella formosa* were considered to be planktonic. All other taxa were considered to be benthic, except for *Fragilaria capucina* and *Fragilaria construens var. venter* which are tychoplanktonic. Two analyses were made by lumping these taxa first with the planktonic forms, then with the benthic.

C. Loss on Ignition (LOI)

The LOI method used was modified from Dean (1974). A sample of sediment that contains organic material and calcium carbonate is first dried to remove all moisture. When this desiccated sample is heated in a muffle furnace, the organic material starts to burn at approximately 200° C, and has completely ignited by the time the furnace reaches approximately 550° C. Beginning at around 800° C, the CO_2 present in calcite starts to ignite, and most of the CO_2 in the sample has been burned off by the time the furnace reaches a temperature of 850° C. Unlike calcite, dolomite begins to burn at temperatures around 700-750° C. However, the distinction between the calcite and dolomite cannot be determined from the results of loss on ignition (Dean 1974). The two are considered together as carbonates. All runs of this LOI test were performed with one replicate, with the crucibles left uncovered.

1. Preparation

Each empty crucible was weighed (**crucible weight**). Small (~1 g) amounts of thoroughly mixed wet sediment were placed in individual ceramic crucibles for each interval of Core C. Each crucible+wet sediment was weighed (**wet weight = (wet weight + crucible weight) - crucible weight**). The crucibles were placed uncovered in the drying oven overnight (for more than 12

hours). The oven was at a temperature of <100° C. Each crucible+dry sediment was weighed (**dry weight = (dry weight + crucible weight) – crucible weight**).

2. Loss On Ignition

A Thermolyne (FA1730-1) muffle furnace with a Type 53600 Furnatrol II temperature controller was programmed to heat up to 550° C, remain at temperature for one hour, then cool down to 30° C. After ignition, the crucibles were cooled in desiccators to room temperature, then weighed (**ash weight 1= (ash weight 1 + crucible weight) – crucible weight**). This procedure was repeated for a temperature of 1000° C (**ash weight 2= (ash weight 2 + crucible weight) – crucible weight**).

3. Calculations

$$\textbf{\% Moisture} = \frac{\text{wet weight - dry weight}}{\text{wet weight}} \times 100$$

$$\text{\% LOI at 550° C} = \frac{\text{dry weight – ash weight 1}}{\text{dry weight}} \times 100$$

$$\text{\% LOI at 1000° C} = \frac{\text{dry weight – ash weight 2}}{\text{dry weight}} \times 100$$

% LOI at 1000° C - % LOI at 550° C = % CO_2 (mostly from $CaCO_3$)

$$\textbf{\% Organic Carbon} = \frac{\text{\% LOI at 550° C}}{2.13}$$

$$\textbf{\% Carbonates} = \frac{\text{\% LOI at 1000° C - \% LOI at 550° C}}{0.44}$$

% Silicates+ = 100 - (% Moisture + % Organic Carbon + % Carbonates)

The stratigraphy of each of these percent values was plotted using TILIA (Grimm 1991, 1992).

D. Charcoal

1. Preparation

Since charcoal is organic in nature and in order to conserve as much as possible of the remaining material in the almost depleted sediment samples, a typical palynology preparation was used, anticipating that the resultant slides will later be used for a palynological analysis as well. Approximately 2-3 g of wet sediment from Core C were placed in individual 50 mL plastic centrifuge tubes. Sediments from were first treated with 25% HCl in order to remove any

carbonates. The samples were washed with distilled water, carefully treated with 40% HF, and neutralized. Each of the 24 unsieved digested fractions was placed in small labeled glass vials. Two drops of phenol solution were added to each vial to prevent the growth of fungi.

Each sample was then sieved with distilled water through a small square of 10 μm Nitex mesh; a few mL of Darvan #4 were added to assist in the breakup of amorphous organic matter (AOM). The sieved residue was then placed in small labeled glass vials. Two drops of phenol solution were again added to each vial to prevent fungal contamination.

One drop of the sieved residue and one drop of Cellosize (R.I.=1.50-1.51) were thoroughly mixed on one side of a glass cover slip for each interval. The dry cover slips were mounted on microscope slides using Elvacite.

2. Microscopy

The ocular micrometer of a Leica DMRB microscope was calibrated using a stage micrometer. The charcoal fragments were divided into size classes based on longest axis (Mehringer et al. 1977). Mehringer et al. (1977) discerned two patterns in the size distribution of charcoal fragments. First, when fragments ≤25 μm were abundant, charcoal of all of the other size classes was also more abundant. Also, most charcoal larger than 25 μm fell into the 25-50 μm size class. The following size classes were used in the charcoal analysis of Mirror Lake: <25 μm, 25 to <50 μm, 50 to <75 μm, 75 to <100 μm, 100 to < 125 μm, 125 to < 250 μm, and 250 μm +.

Charcoal fragments were counted if they were black, opaque angular fragments. For the first few intervals, the entire slide was counted. At interval 14-15 cm, a maximum of 600 fragments were counted. The stratigraphy of this data set was plotted using TILIA (Grimm, 1991, 1992). A Leica DMRB microscope (100X oil objective) and an RS-Photometrics CoolSnap digital camera were used to capture images of sample charcoal fragments.

IV. RESULTS

A. Field Data

Field data was collected on 12 of the 15 study lakes (the need to split into two sampling teams to complete the project resulted in sacrificing the field data on Minam, Blue, and Upper Lakes [Table 1]). Most lakes were moderately to highly transparent with Secchi disk values ranging from 7.2 m to 12 m for those lakes where the disk was not visible on the lake bottom.

The lake with the lowest transparency (other lakes had lower Secchi-disk values, but the disk was visible on the lake bottom), Glacier Lake (7.2 m), was noteworthy because of the visible turbidity, apparently a product of glacial or snowfield inflow. Mirror Lake, the subject of the paleolimnological study, was typical of the study lakes, with a transparency of 10 m.

Lake surface temperatures averaged about 12°C in which case it was likely that the lakes were homothermic or approaching mixis. Specific conductance and pH values measured in the field were generally comparable to values measured in the laboratory (Table 2), although we had greater confidence in the laboratory values for pH and conductivity and have reported these instead of the field observations.

B. Analytical Results

1. Quality Assurance

The quality of the major ion chemistry was assessed using one blank sample, two duplicate lake samples, and checks of internal consistency (Appendix A). The blank sample (BLA) showed measurable concentrations of calcium, sodium, ammonia, and fluoride. Both the Ca^{2+} and Na^{2+} concentrations were low (< 4 μeq/L). The NH_4^+ value was 1 μeq/L, which was slightly less than the 1 to 2 μeq/L measured in the lake samples. This suggests a slight positive bias in the NH_4^+ results. The most noteworthy ion measured in the blank samples was F^- (6 μeq/L). No F^- was measured in the lake samples and we have no explanation for the observed value. Since F^- does not seem to be present in the lake samples, it appears this anomaly has no impact on the results.

The analysis of the two duplicate lake samples for Moccasin Lake showed no substantive differences among the results. However, for Sunshine Lake, both Ca^{2+} and SO_4^{2-} showed significant differences between duplicates. Furthermore, the SO_4^{2-} results of 26 μeq/L for sample SUN-01 was a clear outlier (72x the next highest value). SUN-01 was rejected for interpretation because the deviation between measured and theoretical conductivity was 24%, again almost twice as great as the next highest percent difference. The results in the following section are based on those from SUN-02.

Internal consistency among sample results was checked by comparing traditional indicators of quality for major ion chemistry (Appendix A). Comparisons of ion balance as indicated by a plot of anions versus cations showed good agreement for the lake samples (Appendix A). Comparison of measured vs theoretical conductivity also showed reasonable agreement,

Table 2. Field Data for Eagle Cap Study Lakes.									
Lake	Sample ID	Date	Time (24 hr)	Latitude Deg./Min	Longitude Deg./Min	Temp (°C)	Secchi Disk (m)	Specific Cond. (µS)	pH
Mirror	MIR-01	9/22/98	1615	45.17923	117.30972	12.7	10	8.5	7.58
Razz	RAZ-01	9/23/98	1147	45.21284	117.27633	13	6.4B	8	7.08
Unnamed	BEN-01	9/23/98	1322	45.21115	117.28629	9.6	sh	5	6.96
Horseshoe	HOR-01	9/23/98	1512			14.6	9.9	10.5	7.38
Lee	LEE-01	9/23/98	1620	45.19721	117.2795	14.3	12	14.9	7.28
Crescent	CRE-01	9/23/98	1730	45.19622	117.28489	12.8	NM	13.1	7.88
Craig	CRA-01	9/23/98	1758	45.1957	117.2914	11.9	sh	5.4	6.99
Douglas	DOU-01	9/23/98	1820	45.19508	117.2942	13.5	9.8	11.6	7.36
Glacier	GLA-01	9/24/98	1100	45.16372	117.2844	10.3	7.2	7.8	7.77
Prospect	PRO-01	9/24/98	1230	45.15702	117.27997	10.9	7.6	5.1	7.31
Moccasin	MOC-01 MOC-02	9/24/98	1515	45.18121	117.30072	13.6	11.3	8.1	7.51
Sunshine	SUN-01 SUN-02	9/24/98	1730	45.18255	117.30689	11.9	sh	11.8	7.76
Minam	MIN-01	9/23/98	1400			None Collected			
Blue	BLU-01	9/23/98	1300			None Collected			
Upper	UPP-01	9/23/98	1000			None Collected			

excepting the deviation for sample SUN-01 as noted previously. There appears to be a slight positive bias in measured conductivity relative to theoretical values, although this may be an artifact of not including some unmeasured ions in the calculation. Measured ANC versus calculated alkalinity (C_B-C_A) shows close agreement providing some indication that measurement of major ions and ANC are both acceptable. Measured versus calculated pH shows values within 0.3 pH units of one another, which given the uncertainties in both the measured and the estimated pCO_2 value, seems reasonable. Measured pH versus measured ANC shows values within the expected range for these samples. Sodium versus chloride is often a close relationship in freshwaters that receive marine aerosols and little input of sodium from weathering. Neither of these cases apply here, but most lakes show a reasonably close agreement for Na^+ vs Cl^-. The one exception is Blue Lake, which has a measured Cl^- value of 10

$\mu eq/L$, far above the values for the other study lakes. Other measures of internal consistency show no deviations for BLU-01. Thus, although the measured Cl^- concentration for Blue Lake is suspicious (based on the population distribution), we have no basis for eliminating it from the reported results. In summary, the analytical lake chemistry data appears to be of high quality and acceptable for use in this assessment.

2. <u>Lake Chemistry</u>

a. pH and ANC

pH and ANC are the two parameters most often considered when assessing lake sensitivity to atmospheric inputs, particularly from acid anions (SO_4^{2-}, NO_3^-). The pH distribution for the study lakes shows a very narrow range of observed values, and none less than pH 6.6 (Figure 2). Similarly, the observed range of ANC values is fairly restricted (59 to 196 $\mu eq/L$) and well above those values typically associated with highly sensitive aquatic resources (Figure 3).

b. Major ions

The major anion in the study lakes was bicarbonate (HCO_3^-) with minor contributions from sulfate (SO_4^{2-} and Cl^-). Sulfate concentrations were less than 13 $\mu eq/L$ in all lakes with a median value of 4 $\mu eq/L$ (Figure 4). Chloride concentrations also were low with a median concentration of less than 2 $\mu eq/L$ (Figure 5). Silica, which can be present as an anion, was of moderate concentration (Figure 6). The pH of the lakes and the close balance of measured anions and cations indicates that most of the silica is probably amorphorous silica and does not play a significant role in the ion chemistry of these lakes. The dominant base cation was calcium (Ca^{2+}), followed in decreasing order of relative importance by sodium (Na^+), magnesium (Mg^{2+}), and potassium (K^+) (Figure 7). Calcium values typically exceeded the concentrations of the sum of Mg^{2+}, Na^+, and K^+.

c. Nutrients

Total phosphorus concentrations ranged from 3 to 45 $\mu g/L$ with a median value of 8.5 $\mu g/L$ (Figure 8). Seven of the 15 lakes sampled had phosphorus concentrations greater than or equal to 10 $\mu g/L$, a value sometimes associated with more productive lakes. The highest TP value , 45 $\mu g/L$, was measured in Crescent Lake, a lake which also had the highest ANC, pH, and silica.

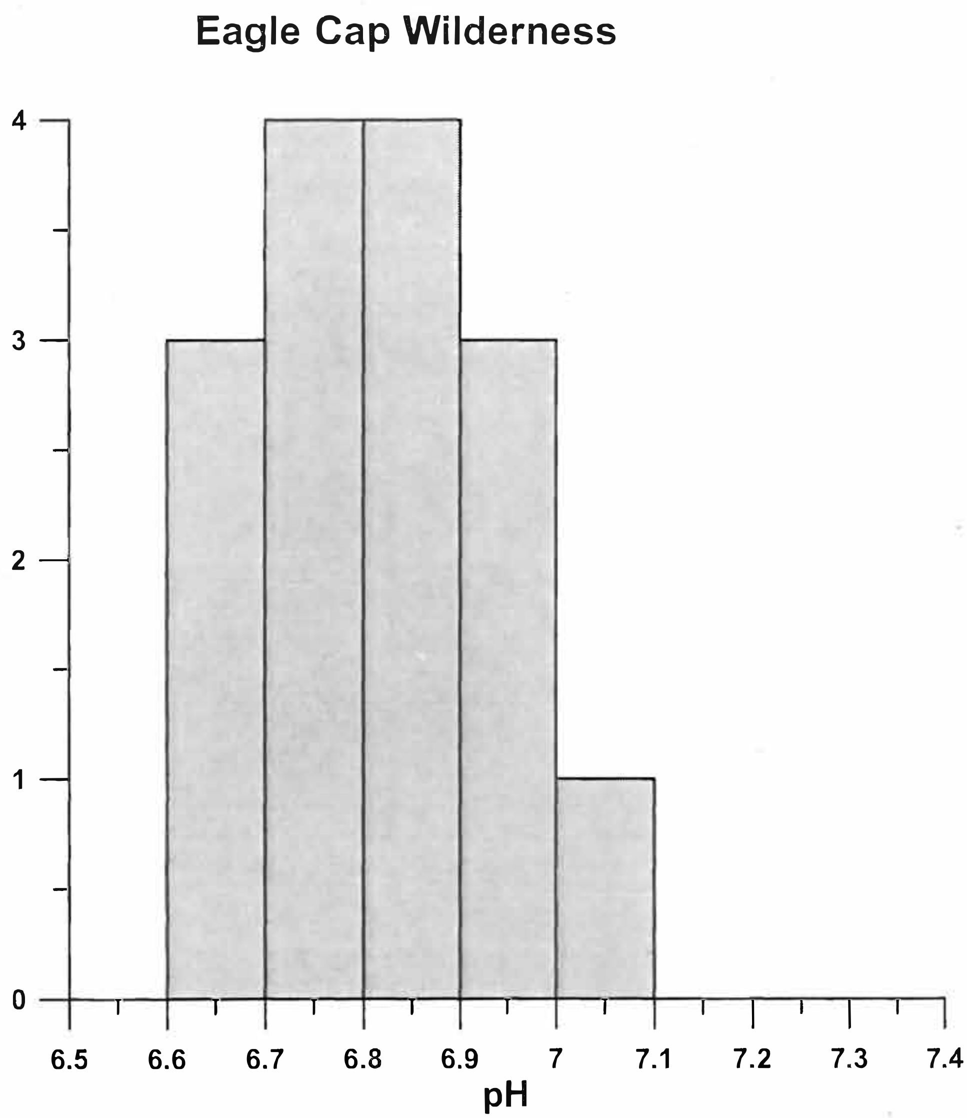

Figure 2. Histogram of laboratory pH for Eagle Cap Wilderness lakes sampled in September 1998. The Y axis shows the number of lakes within a specified pH interval. The pH intervals are indicated on the X axis.

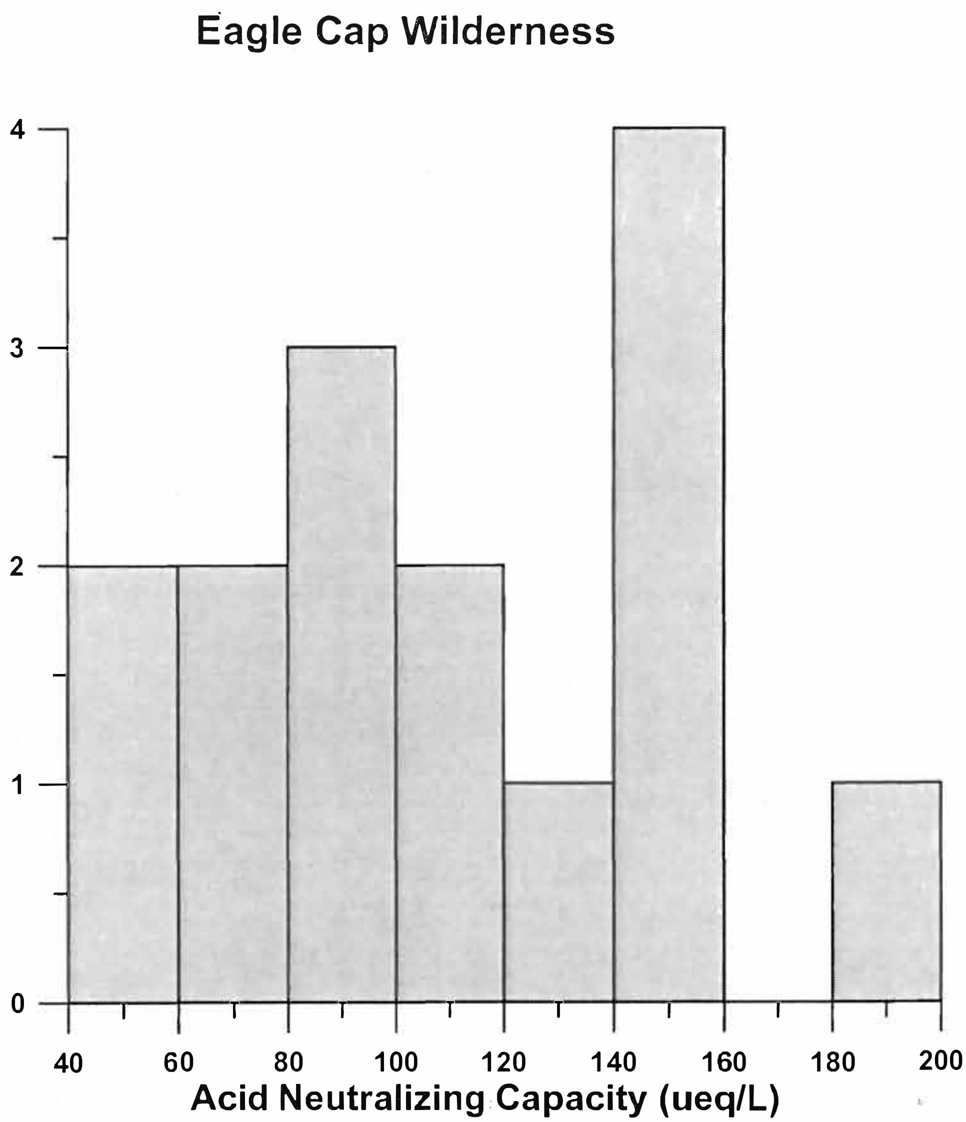

Figure 3. Histogram of acid neutralizing capacity values (ANC, µeq/L) for Eagle Cap Wilderness lakes sampled in September 1998.

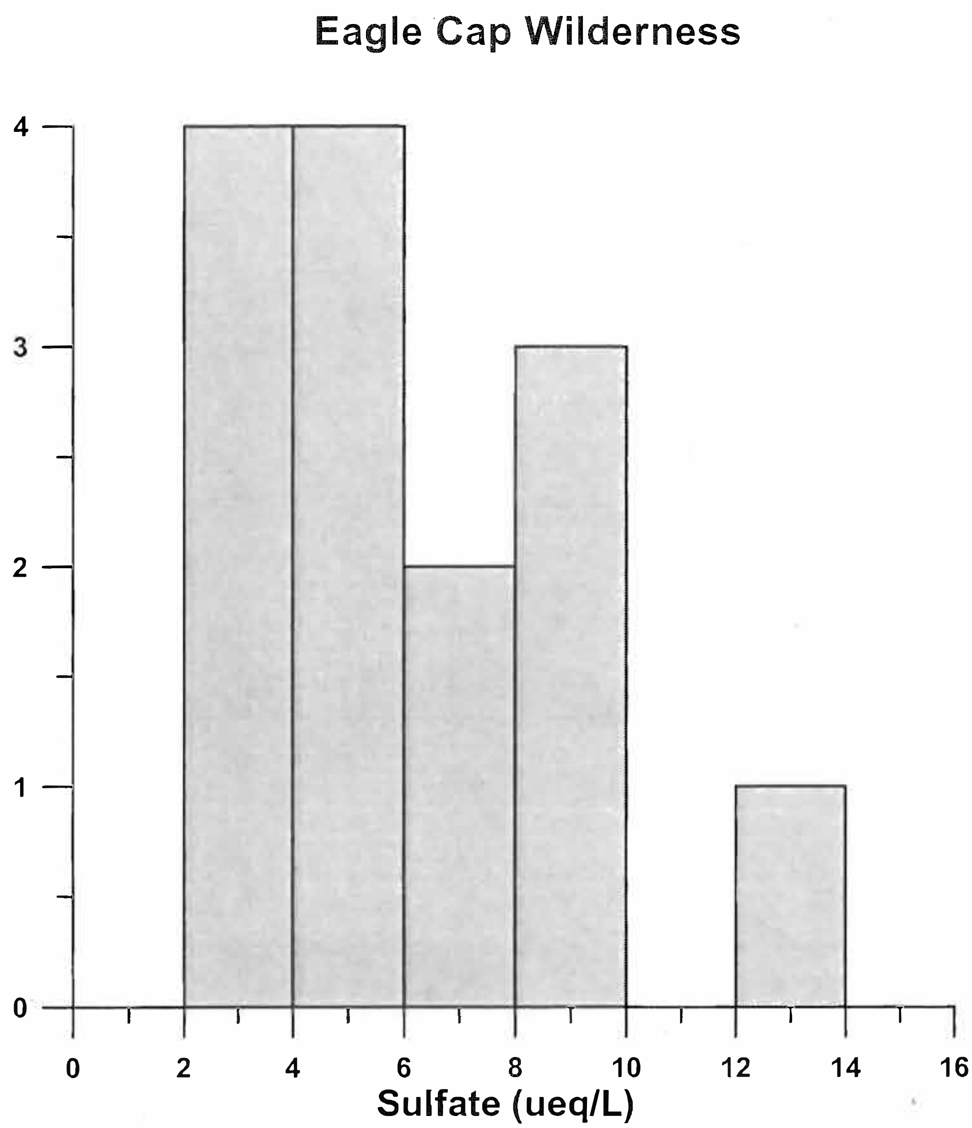

Figure 4. Histogram of sulfate concentrations (μeq/L) for Eagle Cap Wilderness lakes sampled in September 1998.

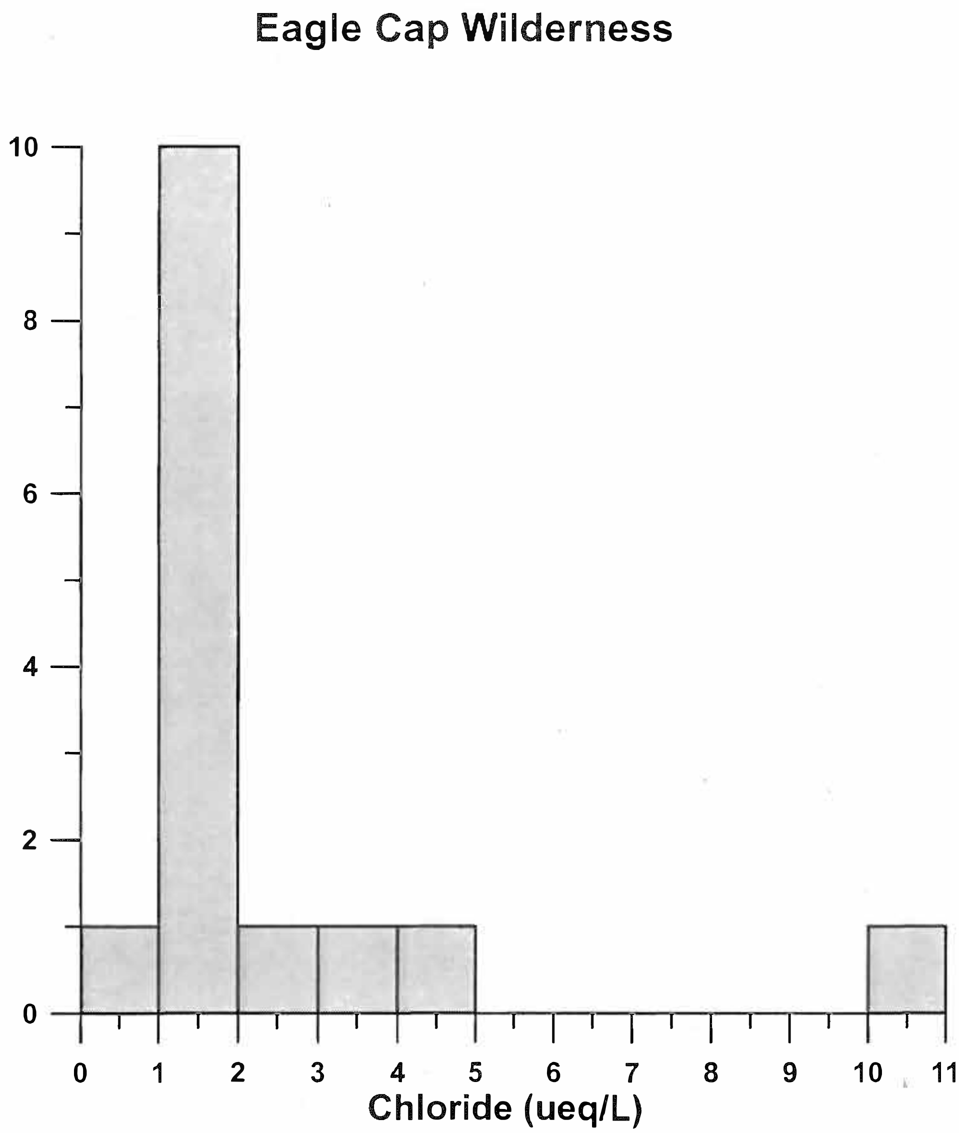

Figure 5. Histogram of chloride concentrations (μeq/L) for Eagle Cap Wilderness lakes sampled in September 1998.

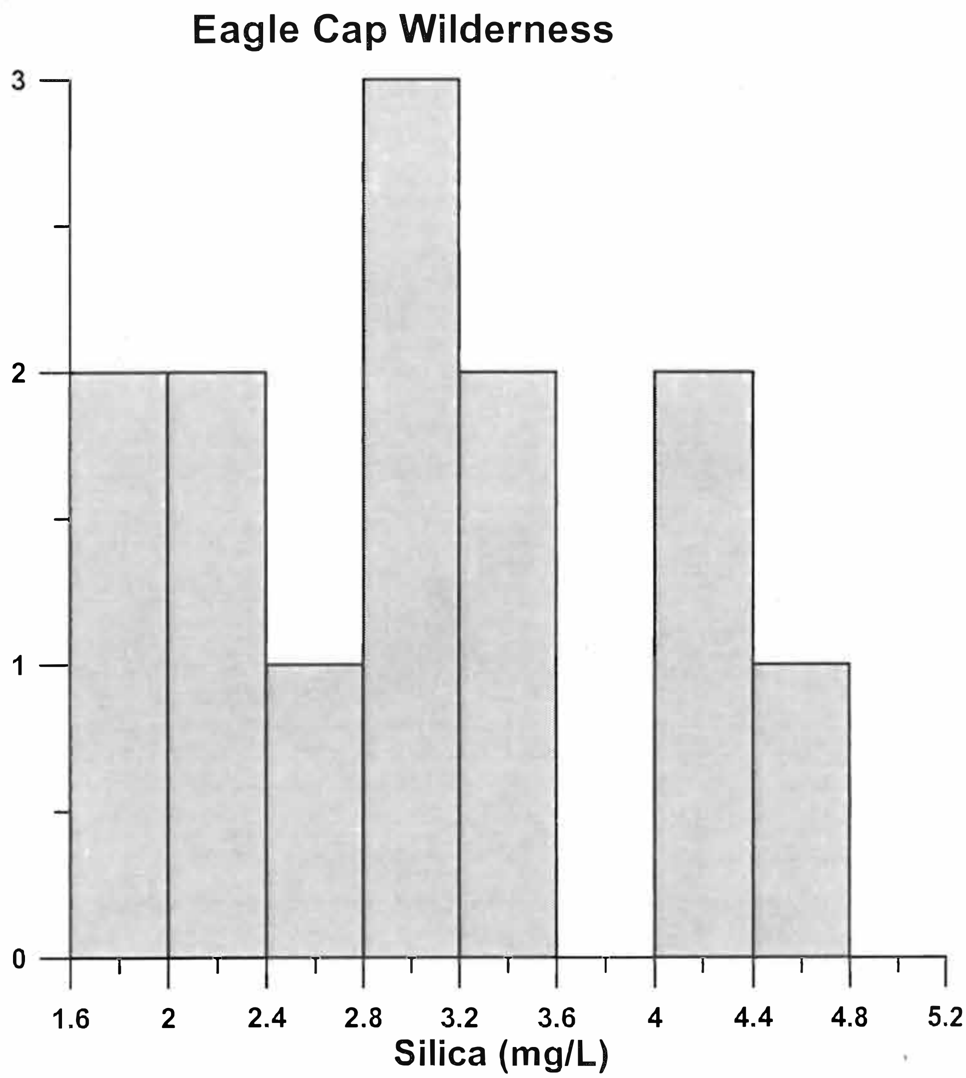

Figure 6. Histogram of silica concentrations (mg/L) for Eagle Cap Wilderness lakes sampled in September 1998.

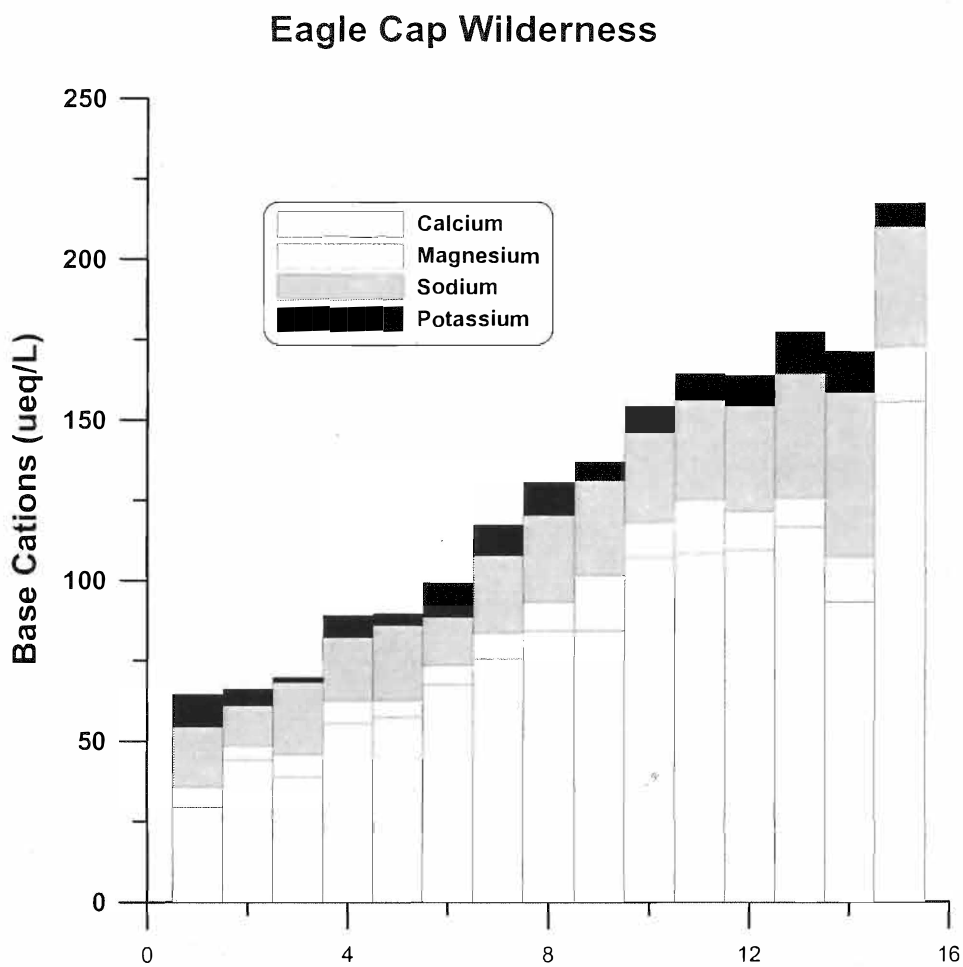

Figure 7. Base cation concentrations (μeq/L) for Eagle Cap Wilderness lakes sampled in September 1998. The observations are sorted for the study lakes in increasing concentrations of base cations indicated on the Y axis. The concentrations of the four principal base cations are shown for each of the sampled lakes.

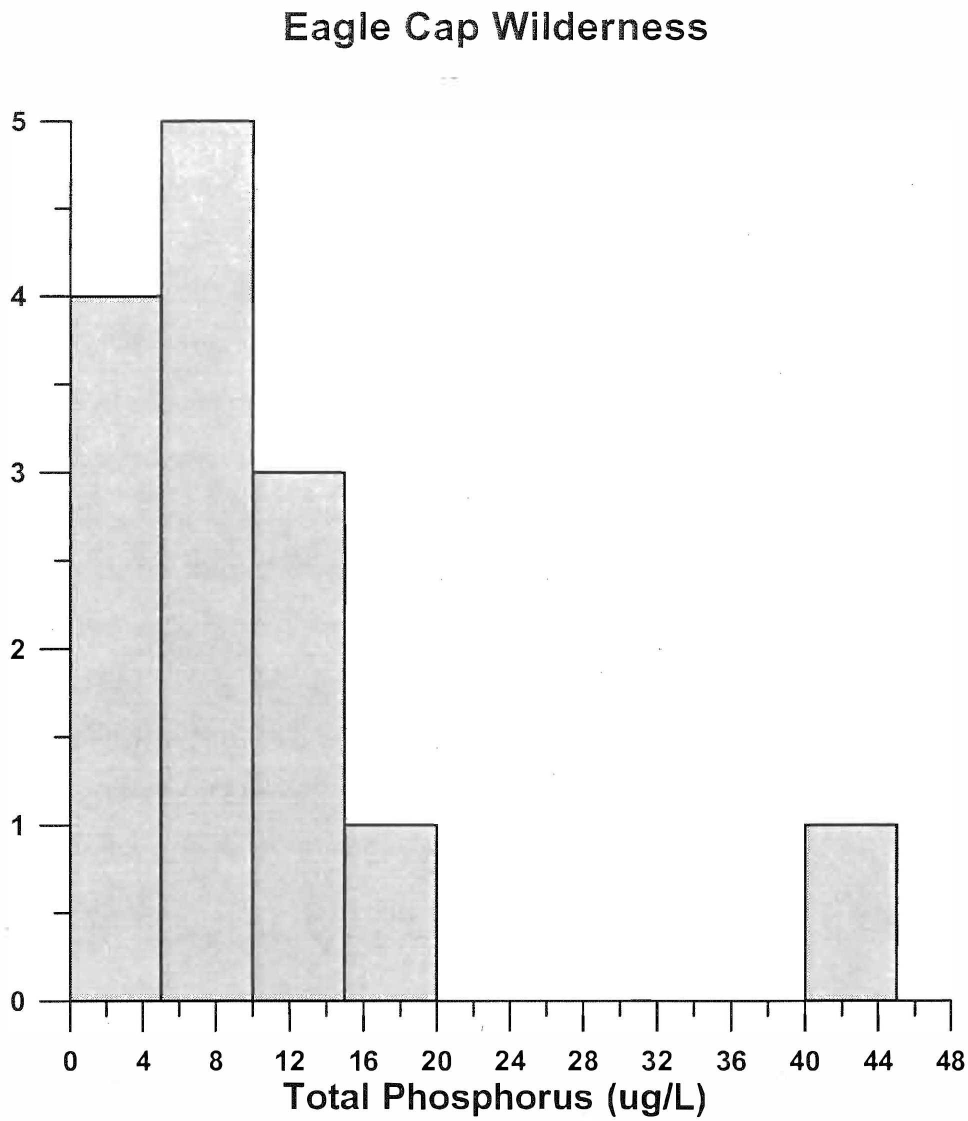

Figure 8. Histogram of total phosphorus concentrations (μg/L) for Eagle Cap Wilderness lakes sampled in September 1998.

Inorganic nitrogen was not abundant in the study lakes. Ammonium (NH_4^+) values barely exceeded the detection limit (1 to 2 μeq/L) and nitrate (NO_3^-) was not detected in these fall samples.

Silica, which can sometimes limit diatom production, was generally present in sufficient quantities to provide relatively unrestricted growth of this class of algae.

C. Phytoplankton

Algal biovolume in the study lakes ranged from 17,000 to 121,000 cu µM/ml with a median of 46,000 cu µM/ml (Figure 9). The lake with the lowest biovolume, Upper Razz Lake, was dominated by *Rhodomonas minuta* which represented 79% of the biovolume and 95% of the density in the lake. Only four taxa were counted in the Upper Razz Lake sample, resulting in a diversity index of 0.36. The most productive lake (based on biovolume), Craig Lake, had a far more diverse taxa (DI=2.35), yet a major component of the biovolume (27%) was comprised of the cyanobacteria *Anabaena planktonica*. The most diverse assemblage (based on DI) was present in Minam Lake, a reservoir at the headwaters of the Lostine River. Mirror Lake had the second-highest biovolume (102,000 cu µM/ml) which was dominated by two taxa, *Oocystis pusilla* (70%) and *Sphaerocystis schroeteri*. It would be tempting to characterize the algae in Mirror Lake as unusual; however, the variation in taxonomic diversity among the study lakes is so great that it is difficult to define a "typical" algal assemblage for the area (Figure 10). When examining the most abundant taxa, three of the lakes had *Melosina distans* as the dominant, two lakes had *Oocystis pusilla*, two had *Sphaerocystis schroeteri*, two had *Selenastrum minutum*, and the remaining lakes all had different dominant taxa. Complete results for individual lakes are presented in Appendix B.

D. Paleolimnology of Mirror Lake

1. Core Description

Four Glew minicores were recovered from Mirror Lake, three of which were sent to the Paleoenvironmental Assessment Laboratory (PAL), Department of Geology, University of Toronto, for analysis. The cores were recovered from two basins (the East basin) from a depth of *ca.*16-17 m. The following core descriptions are modified from Eilers (1998). Core B was a totally undisturbed core, 7 cm in length, with a distinct orange-red iron oxide layer in the first 0.5 cm. The sediments of Core B show minimal disturbance; this core has been archived in PAL. Core A was 29 cm in length, and Core C was 24 cm in length. In Core A and Core C, the first *ca.* 5 cm of sediment are tinged with an orange-red color as a result of mixing in the upper layers of sediment. There was no sulphur smell and presumably the sediments are well oxidized. Generally, the rest of each core is a homogenous grey-green material with a high proportion of algal remains. There may be some fine clays from the breakdown of metamorphic granitic

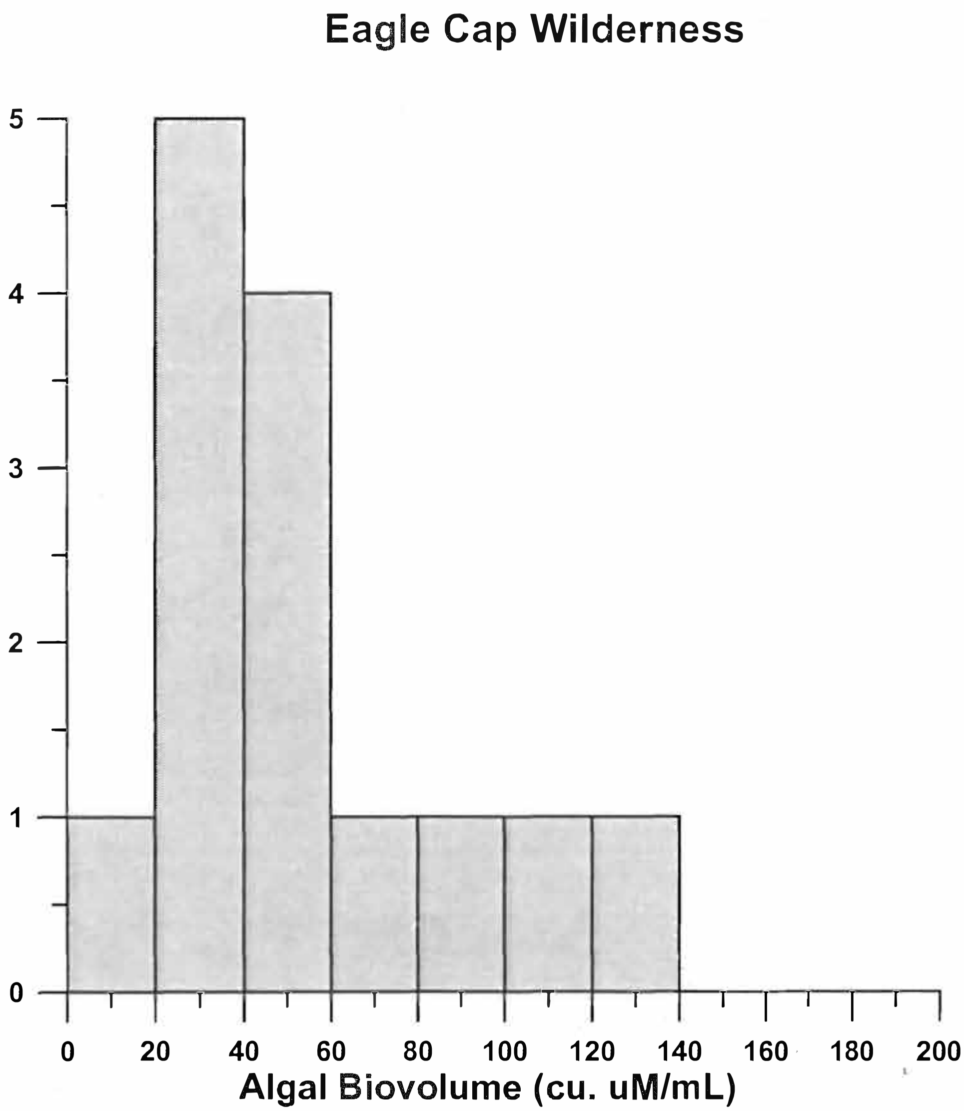

Figure 9. Histogram of algal biovolume (cu µM/mL) for Eagle Cap Wilderness lakes sampled in September 1998.

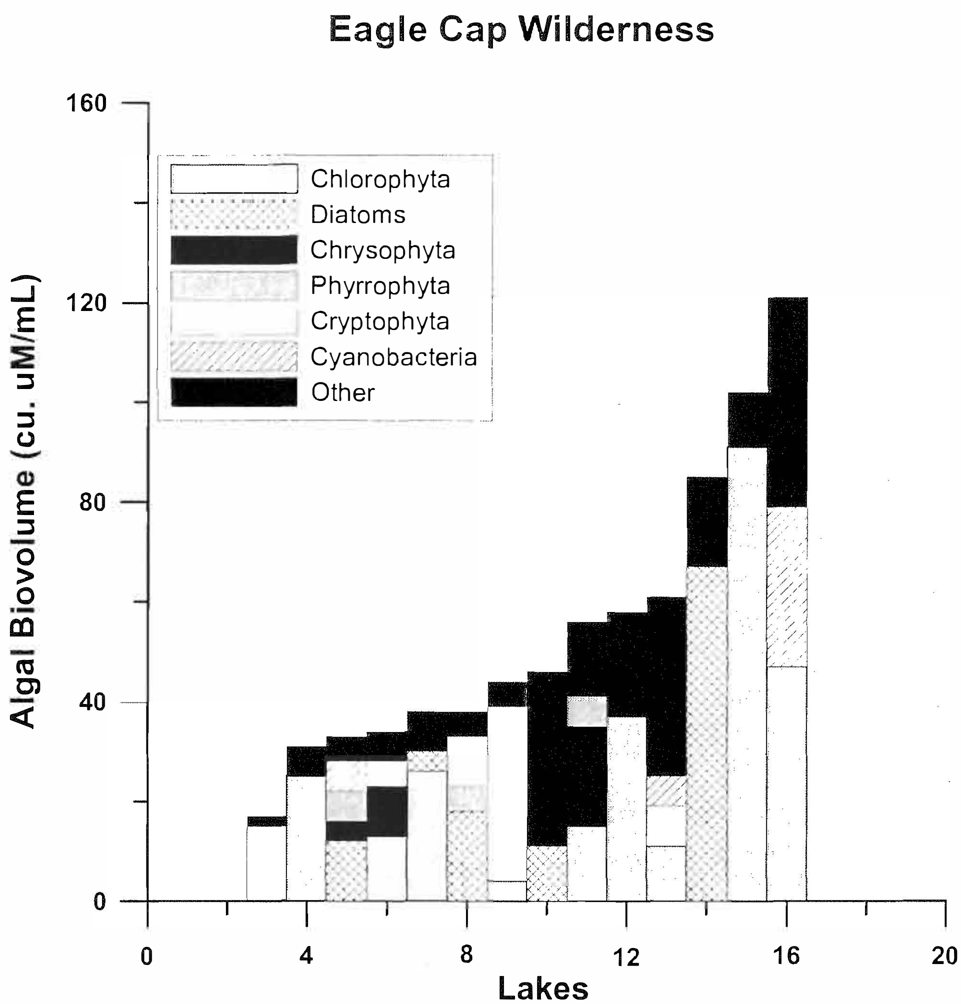

Figure 10. Dominant phytoplankton groups shown for lakes in the Eagle Cap Wilderness sampled in September 1998 sorted by increasing biovolume. Note that data for two lakes are missing (plankton data not sampled). The bar for each lake illustrates, the biovolume of algal groups shown in the inset key. The figure illustrates the variable algal composition among the study lakes.

material in the catchment. There was no evidence of bioturbation, no chironomid tubes, and no large pieces of debris.

2. Sediment Dating and Sediment Accumulation Rates

Age of the sediments was determined using ^{210}Pb methodology for the recent history and ^{14}C to characterize the age at the base and middle of the sediment core. The upper sediments show that the activity of ^{210}Po approaches background or "supported" values near a depth of 10 cm in the lake sediment (Figure 11). When modeled using the CRS model, the results illustrate that the lake sediments at 10 cm depth are approximately 100 years old and that the sediment accumulation rate (SAR) has not been constant (Figure 12). A closer examination reveals that the SAR has averaged about 280 g/m^2/yr, but that the rate over the last 60 years has been less than that occurring from appr●ximately 1900 to 1940.

Age of the sediment at the base and middle of the core showed the ^{14}C dates were 1950 (± 40) YBP (years before present) and 1340 (± 50) YBP, respectively. A plot of age of sediment versus depth for the entire core shows the curves for the ^{210}Pb and ^{14}C dating intercept at 15 cm (Figure 13).

3. Sediment Chemistry

Loss-on-ignition (LOI), organic carbon, carbonates, and silicates are presented in Figure 14. LOI values were generally between 70-85% through a depth of 24 cm. Organic carbon was less than 10% and generally declined slightly frm top to bottom. Carbonates were also near 10%, but no trend was evident with depth. Silicates exhibited a pronounced variation with depth. The upper 5 cm had silicate values generally <5%; from 5 to 16 cm values increased to over 15%, then reached a second minima at 18 cm and increased again to 23 cm. The pattern in silicates followed a similar statistical pattern in diatom community composition which is presented later.

4. Charcoal

Charcoal particles were segregated into six size classes, of which the smallest class represented the majority of the particles (Figure 14). The particle size distributions generally showed few vertical trends, although the 50-75 mm class appears to exhibit a pattern that partitions into three groups corresponding to 0-6 cm, 6-16 cm, and 16-23 cm. Charcoal particles

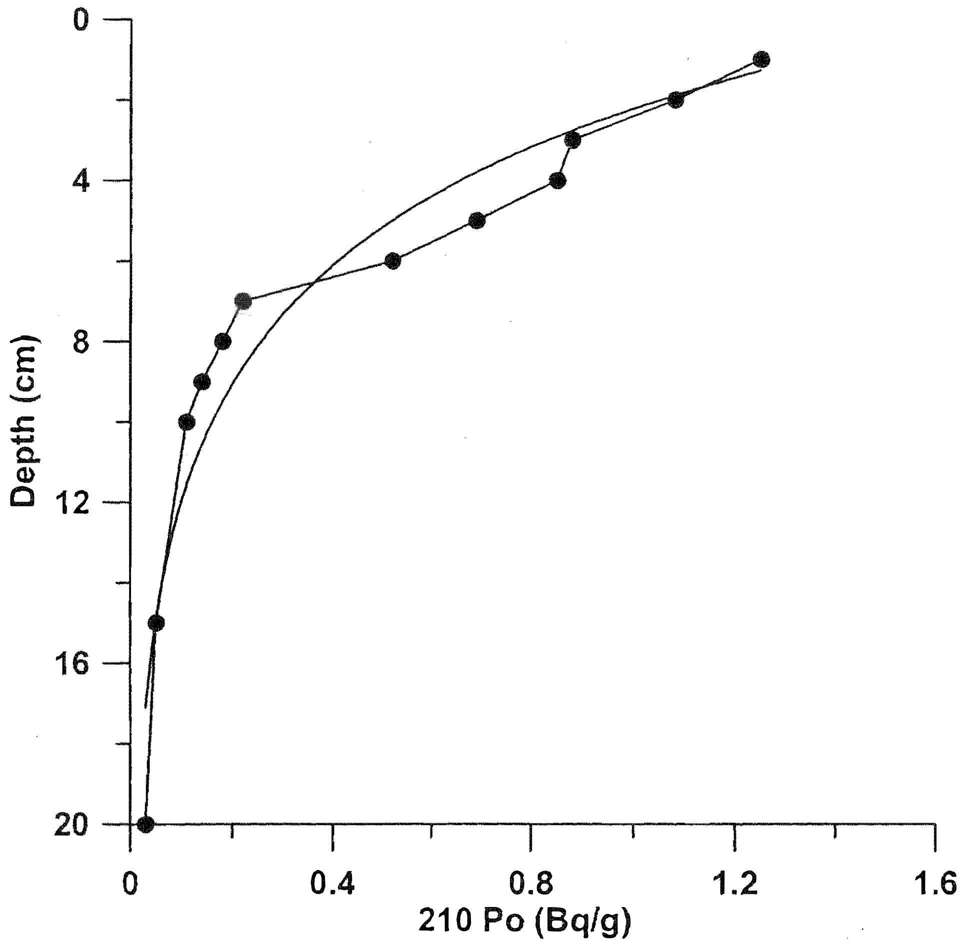

Figure 11. ^{210}Po activity in the sediments of Mirror Lake plotted against sediment depth. The data are presented as raw data and with a polynomial fitted curve.

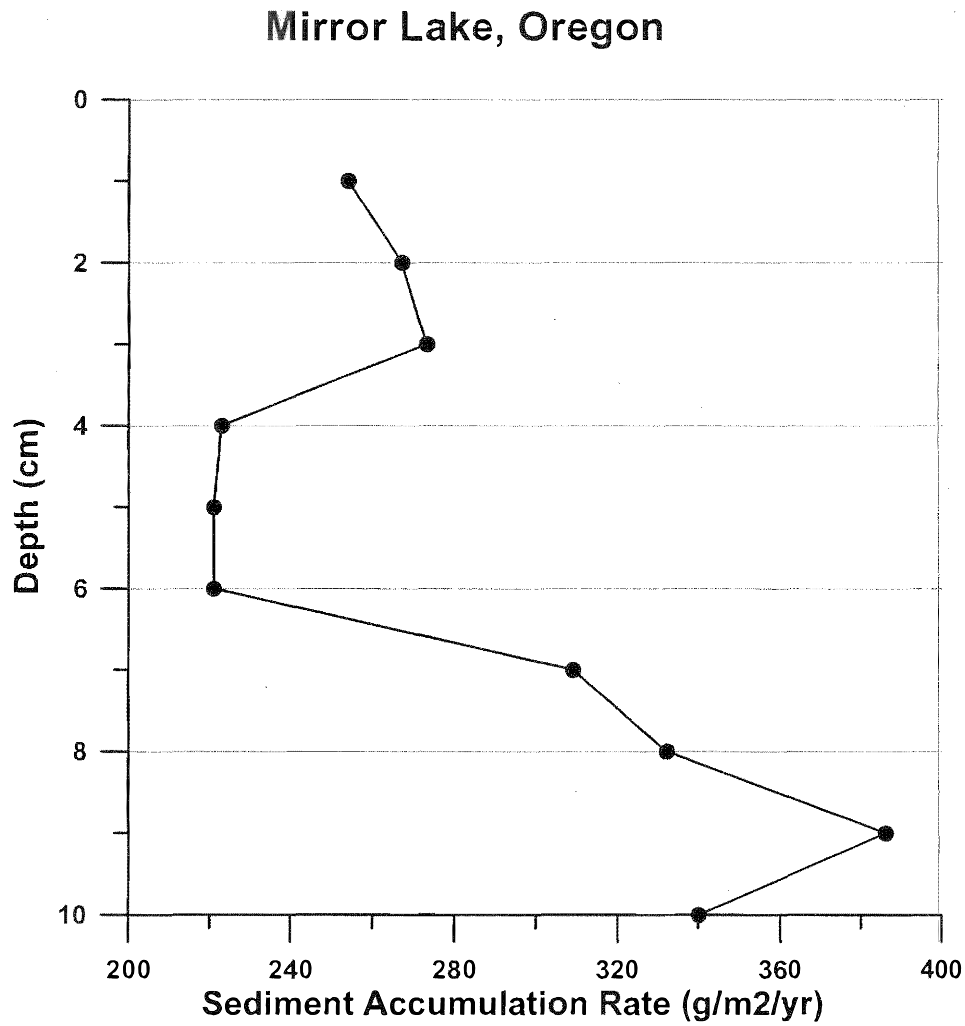

Figure 12. Sediment accumulation rate (SAR; $g/m^2/yr$) for the upper sediments in Mirror Lake computed using the Constant Rate of Supply (CRS) model. Sediment dating provided by MyCore Scientific, Inc.

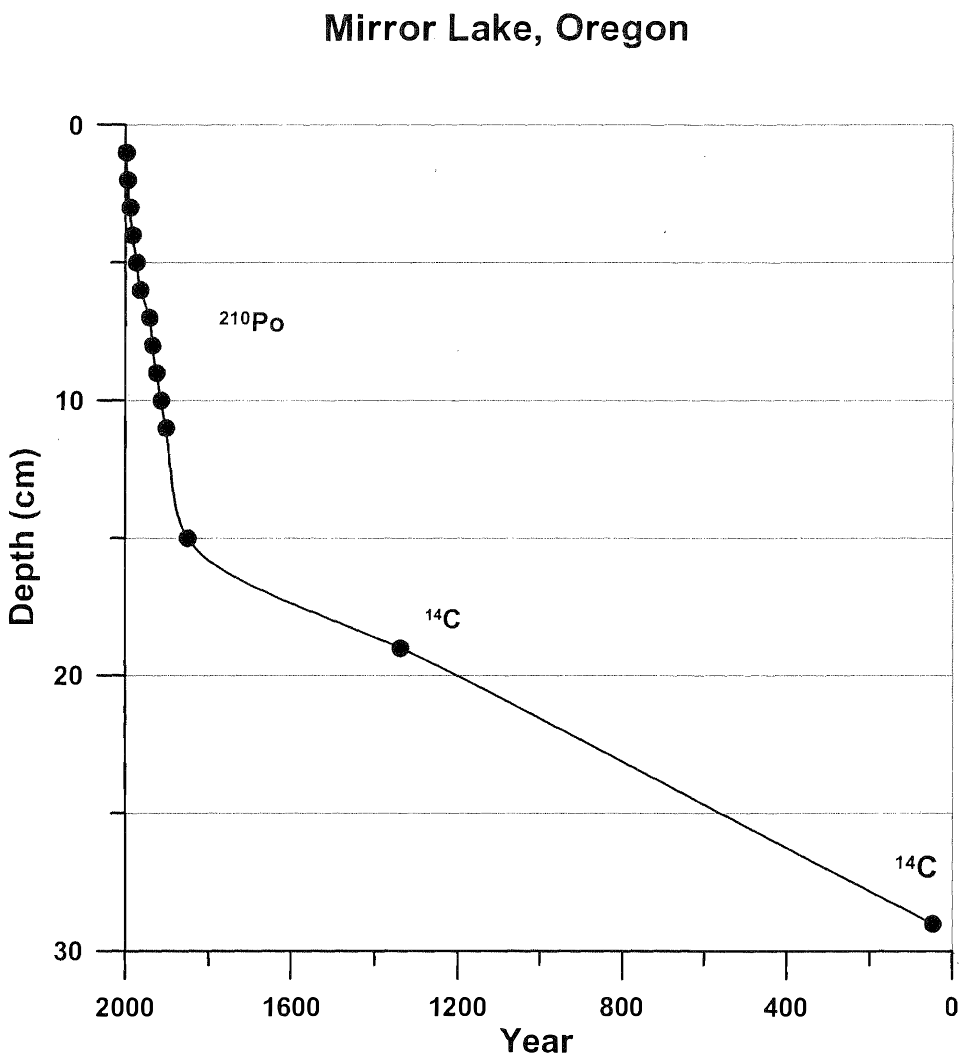

Figure 13. Combined ^{210}Po and ^{14}C sediment dating for Mirror Lake. The change in slope between the two methods indicates that there is a discrepancy in one or both dating techniques, or that there has been a substantial change in the sediment accumulation rate.

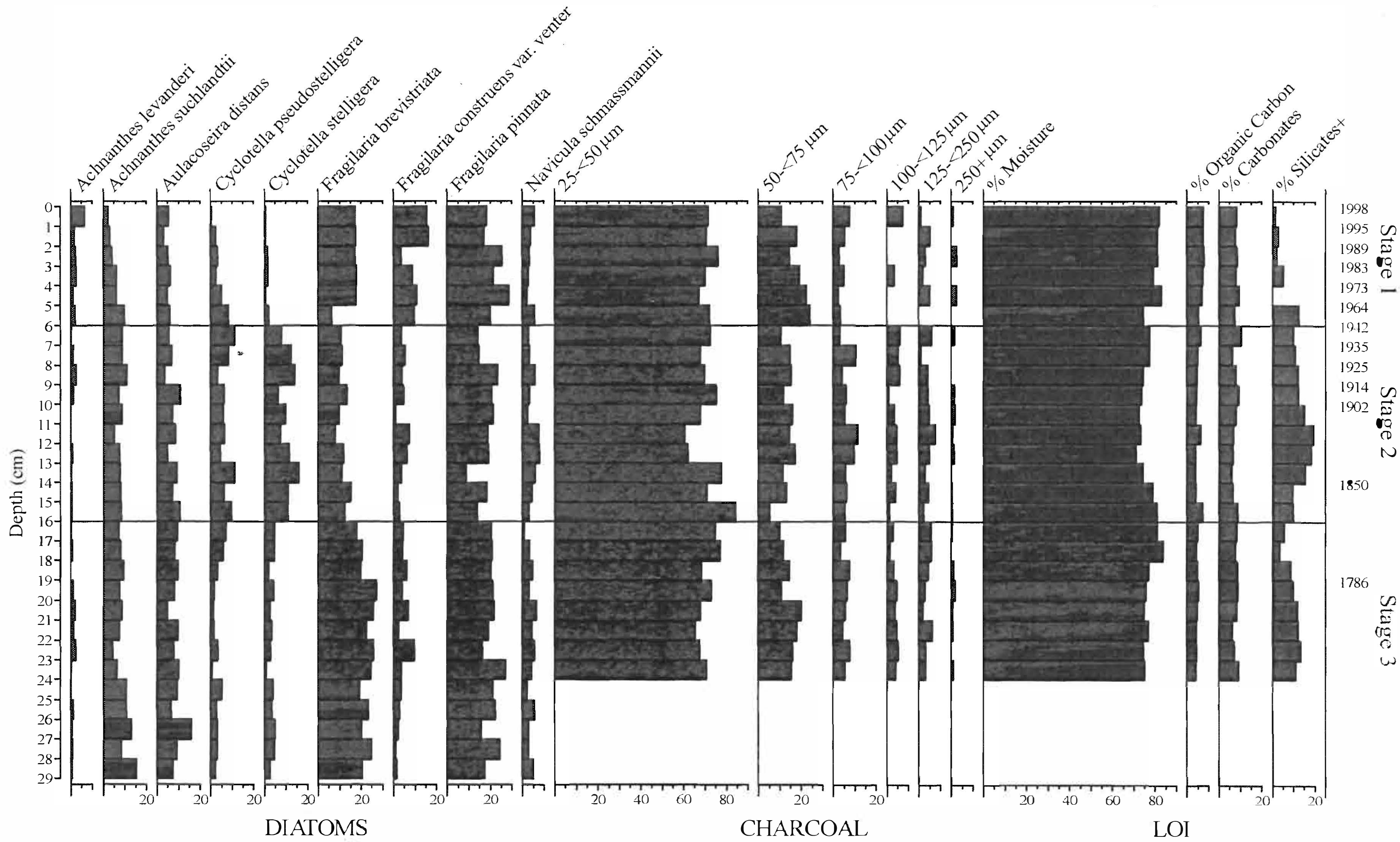

Figure 14. Dominant diatom species, charcoal (partitioned into six size classes), and sediment chemistry (% moisture, % organic carbon, % carbonates, and % silicates) versus sediment depth in Mirror Lake. The three stages are described in the text.

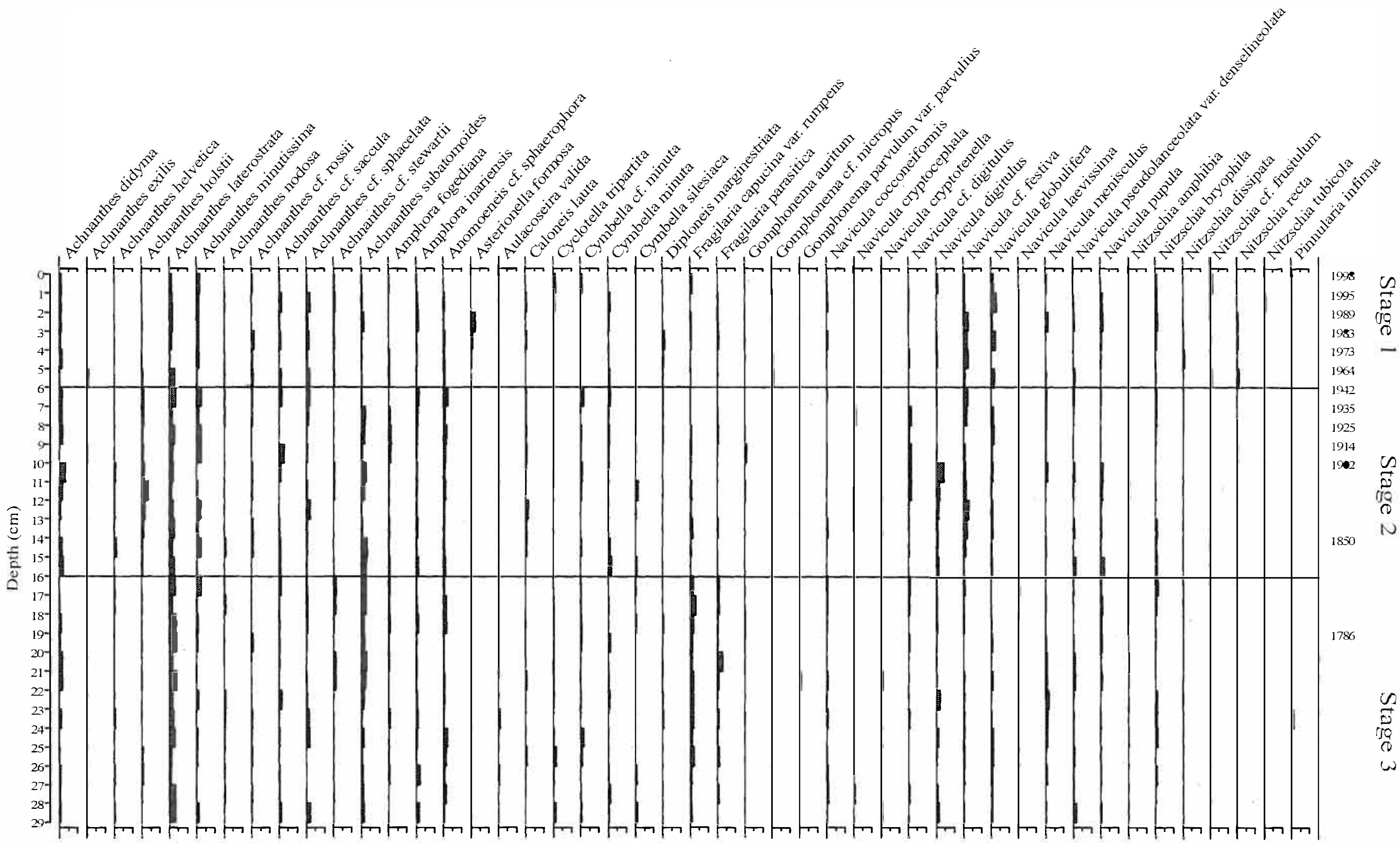

Figure 15. Relative abundances of common (≥ 1%) diatom taxa in the sediments of Mirror lake plotted against sediment depth.

were abundant throughout the core and particles in the largest size class (> 250 μm) were more abundant in the upper sediments (0-5 cm).

5. Diatoms

Figures 14 and 15 show the stratigraphy of the diatoms, loss on ignition, and charcoal analyses. Images of the diatoms and charcoal fragments are included in Appendix C.

The original taxon list of 219 taxa used for counting (before the taxonomy was completely resolved) is shown in Appendix D. The taxonomy was resolved, and screening the data to include only those taxa with a relative abundance of ≥1% in at least one depth interval created a refined list of 55 taxa. Thus, the final data set (Appendix D) consists of 55 taxa. Table 3 lists the abundant taxa with their minimum, mean, and maximum abundances, as well as their number of occurrences in the core. Images of these 55 taxa are included on Plates A through E (Appendix C). Nine of these 55 taxa are present at a relative abundance of at least 5% in one depth interval, and are considered the dominant taxa in this analysis. These dominant taxa are *Achnanthes levanderi*, *Achnanthes suchlandtii*, *Aulacoseira distans*, *Cyclotella pseudostelligera*, *Cyclotella stelligera*, *Fragilaria brevistriata*, *Fragilaria construens var. venter*, *Fragilaria pinnata* and *Navicula schmassmannii*.

Of these nine taxa it is *Fragilaria pinnata* that is generally the most abundant throughout the core. *Fragilaria brevistriata* is almost as abundant as *F. pinnata*. Interestingly, all nine of these dominant taxa are present in all depth intervals except *Achnanthes levanderi*. This species was not observed at 10-11 cm, 11-12 cm, or 18-19 cm.

It is readily apparent from the stratigraphy (Figures 14 and 15) that the diatom assemblage of Mirror Lake has remained relatively stable over time. Several trends, however, can be discerned. Most notably, *Cyclotella pseudostelligera* and *Cyclotella stelligera* increase in abundance between the depth ranges of 5-6 cm and 18-19 cm. There is a slight decrease in abundance in the middle of these two peaks (between the intervals of 9-10 cm and 12-13 cm. However, even at the point of this decline, the abundance remains elevated above apparent background levels. Conversely, the abundance of *Fragilaria brevistriata* is markedly less between these same depth intervals than in the rest of the core.

These are the most striking trends in the diatom stratigraphy. It is interesting to note that all three of *Cyclotella pseudostelligera*, *Cyclotella stelligera* and *Fragilaria brevistriata* are among the most dominant taxa within the data set. Several of the other dominant taxa exhibit trends as

Table 3. Summary statistics for the 55 taxa with at least one occurrence of 1% relative abundance.						
Taxon Code	Taxon Name and Authority	Photographic Plate	MIN (%)	MEAN (%)	MAX (%)	# Occurrences in core
1	*Achnanthes levanderi* Husdtedt	A	0.0	1.3	6.4	26
2	*Achnanthes suchlandtii* Hustedt	A	2.3	8.0	15.3	29
3	*Aulacoseira distans* (Ehrenberg) Simonsen	A	3.3	7.7	15.9	29
4	*Cyclotella pseudostelligera* Hustedt	A	0.6	4.7	11.2	29
5	*Cyclotella stelligera* Cleve & Grunow	A	0.6	5.6	16.1	29
6	*Fragilaria brevistriata* Grunow	A	6.4	17.3	27.2	29
7	*Fragilaria construens var. venter* (Ehrenberg) Grunow (*sensu* Germain)	A	1.2	5.6	16.5	29
8	*Fragilaria pinnata* Ehrenberg	A	8.8	19.8	28.9	29
9	*Navicula schmassmannii* Hustedt	A	0.7	4.2	8.0	29
10	*Achnanthes didyma* Hustedt	B	0.0	1.0	3.2	24
11	*Achnanthes exilis* Kützing	B	0.0	0.1	1.0	3
12	*Achnanthes helvetica* (Hustedt) Lange-Bertalot	B	0.0	0.1	1.2	9
13	*Achnanthes holstii* Cleve	B	0.0	0.5	3.4	18
14	*Achnanthes laterostrata* Hustedt	B	0.5	2.4	4.0	29
15	*Achnanthes minutissima (sensu lato)*	B	0.0	1.0	2.7	23
16	*Achnanthes nodosa* Cleve	B	0.0	0.3	1.0	15
17	*Achnanthes cf. rossii* Hustedt	B	0.0	0.3	1.5	16
18	*Achnanthes cf. saccula* Patrick	B	0.2	0.8	3.0	29
19	*Achnanthes cf. sphacelata* Carter	B	0.0	0.8	2.0	24
20	*Achnanthes cf. stewartii* Patrick	B	0.0	0.3	1.5	15
21	*Achnanthes subatomoides* (Hustedt) Lange-Bertalot & Archibald	B	0.2	1.5	3.4	29
22	*Amphora fogediana* Krammer	C	0.0	0.4	1.5	21
23	*Amphora inariensis* Krammer	C	0.0	0.8	2.2	28
24	*Anomoeneis cf. sphaerophora* (Brébisson) Grunow	C	0.0	0.9	2.4	28
25	*Asterionella formosa* Hassall	C	0.0	0.2	2.5	5
26	*Aulacoseira valida* (Grunow in Van Heurck) Krammer	C	0.0	0.2	1.0	13
27	*Caloneis lauta* Carter & Bailey-Watts	C	0.0	0.2	1.5	12
28	*Cyclotella tripartita* Håkansson	C	0.0	0.3	1.5	17
29	*Cymbella cf. minuta* Hilse	C	0.0	0.4	1.7	18
30	*Cymbella minuta* Hilse	C	0.0	0.6	2.0	24
31	*Cymbella silesiaca* Bleisch	C	0.0	0.2	1.5	10
32	*Diploneis marginestriata* Hustedt	C	0.0	0.1	1.0	10
33	*Fragilaria capucina var. rumpens* (Kützing) Lange-Bertalot	C	0.0	1.0	3.4	25
34	*Fragilaria parasitica* (W. Smith) Grunow	C	0.0	0.5	2.9	18
35	*Gomphonema auritum* A. Braun ex. Kützing	C	0.0	0.1	1.0	3
36	*Gomphonema cf. micropus* Kützing	C	0.0	0.1	1.0	3
37	*Gomphonema parvulum var. parvulius* Lange-Bertalot & Reichardt	C	0.0	0.1	1.0	2
38	*Navicula cocconeiformis* Gregory ex. Greville	D	0.0	0.3	1.0	16
39	*Navicula cryptocephala* Kützing	D	0.0	0.1	1.0	6
40	*Navicula cryptotenella* Lange-Bertalot	D	0.0	0.1	1.0	8
41	*Navicula cf. digitulus* Husdtedt	D	0.0	0.4	1.5	15
42	*Navicula digitulus* Hustedt	D	0.0	0.9	4.2	24
43	*Navicula cf. festiva* Krasske	D	0.0	1.0	3.0	25
44	*Navicula globulifera* Hustedt	D	0.0	0.9	3.0	28
45	*Navicula laevissima* Kützing	D	0.0	0.1	1.0	5
46	*Navicula menisculus* Schumann	D	0.0	0.4	1.7	19
47	*Navicula pseudolanceolata var. denselineolata* Lange-Bertalot	D	0.0	0.5	2.0	21
48	*Navicula pupula* Kützing	D	0.0	0.5	2.0	21
49	*Nitzschia amphibia* Grunow	E	0.0	0.1	1.0	9
50	*Nitzschia bryophila* (Hustedt) Hustedt	E	0.0	0.5	1.5	20
51	*Nitzschia dissipata* (Kützing) Grunow	E	0.0	0.1	1.0	6
52	*Nitzschia cf. frustulum* (Kützing) Grunow in Cleve & Grunow	E	0.0	0.3	1.5	14
53	*Nitzschia recta* Hantzsch	E	0.0	0.2	1.2	12
54	*Nitzschia tubicola* Grunow	E	0.0	0.1	1.0	8
55	*Pinnularia infirma* Krammer	E	0.0	0.1	1.2	8

well (Figures 14 and 15). *Achnanthes suchlandtii* and *Aulacoseira distans* generally increase in abundance downcore. *Fragilaria construens var. venter* is most abundant in the top two centimeters of the core. These dominant taxa are present in relatively high abundances throughout the core.

Several other taxa exhibit interesting trends on a smaller scale (Figure 15). *Achnanthes holstii* is barely present throughout the stratigraphy, but is present in its highest abundances mainly between 6-7 cm and 15-16 cm, and peaks at 12-13 cm. *Fragilaria capucina var. rumpens* is barely present until 16-17 cm and is present in relatively high levels until the last two centimeters of the stratigraphy. *Navicula cf. festiva* and *Navicula globulifera* are both more abundant in the top 16 centimeters of the stratigraphy than in the bottom intervals. Several other taxa are present throughout the core in a seemingly random manner.

An ordination analysis was performed in order to determine if any trends could be statistically determined. Table 4 summarizes the results obtained from this DCA analysis.

Table 4. Summary of the results of the DCA analysis.

Axes	1	2	3	4	Total Inertia
Eigenvalues	0.09	0.04	0.019	0.01	0.42
Gradient Length	1.15	0.86	0.59	0.64	
Cumulative % variance of species data	20.9	30.6	35.0	38.1	
Sum of all unconstrained eigenvalues					0.423

The gradient length of axis 1 from this DCA analysis is 1.15 (see Table 4); this is much less than 4 SD, indicating a strong linear response and that a PCA analysis is appropriate. Table 5 summarizes the results obtained from the subsequent PCA analysis. Figures 16 and 17 show the ordination diagrams for the PCA analysis. The ordination diagrams show three groupings of depth intervals, and indicate which taxa control these groupings. The first two axes cumulatively account for 36.2% of the total variation within the data set. The first axis accounts for 21.7% of the variance, while the second accounts for 14.5%. These numbers are not high, indicating that there are other factors not being considered in this analysis, which account for a greater portion of the variance. This is not surprising, since this ordination is not constrained by any environmental variables. It is very likely that environmental factors account for a large

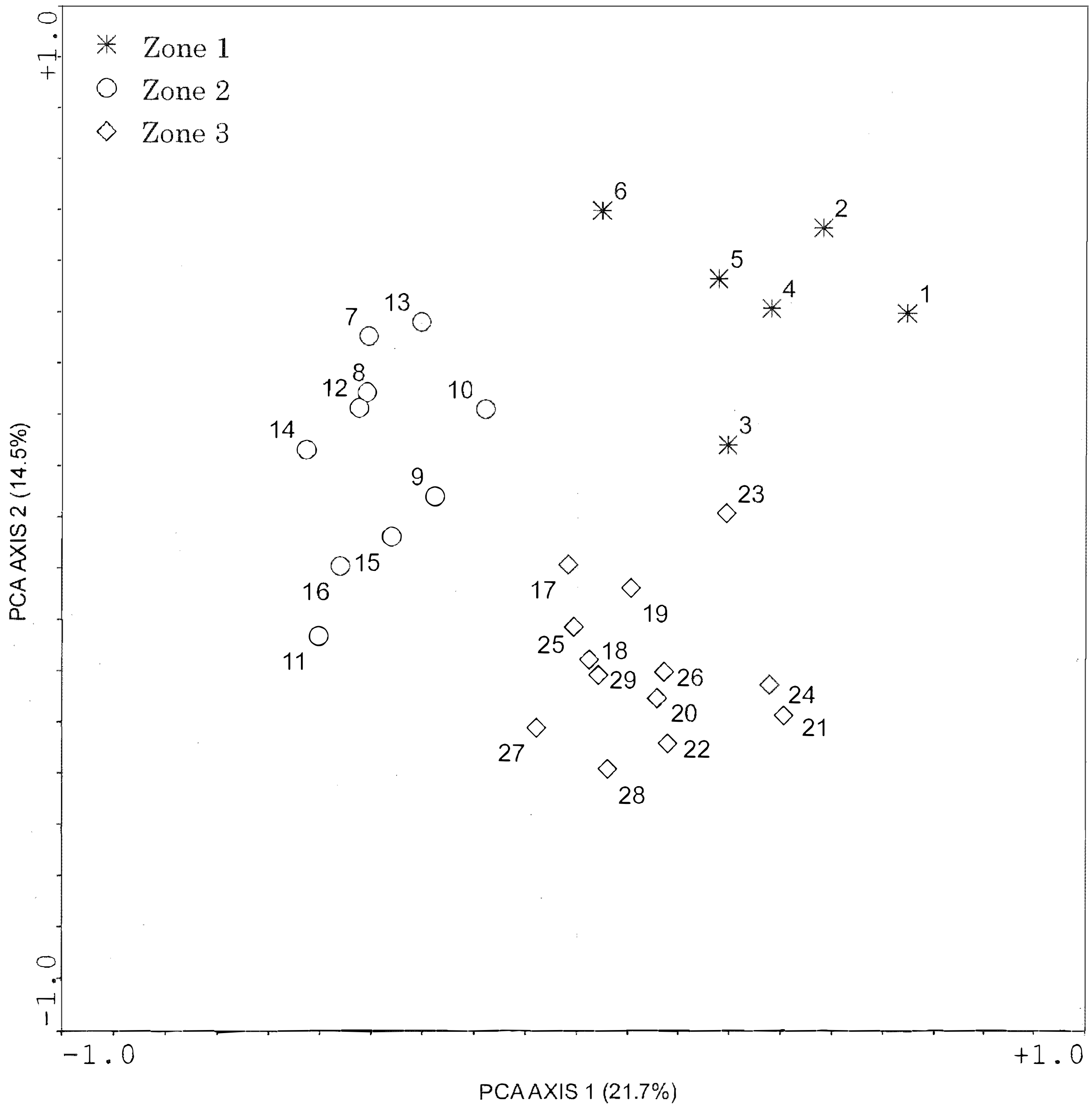

Figure 16. PCA ordination diagram for Mirror Lake sediment intervals. The numbers in the figures correspond to sediment intervals where "1" corresponds to the bottom of the sediment interval 0-1 cm. The three groups of samples correspond to the three stages identified previously in Figure 14. Intervals closest to one another in the ordination diagram are statistically most similar.

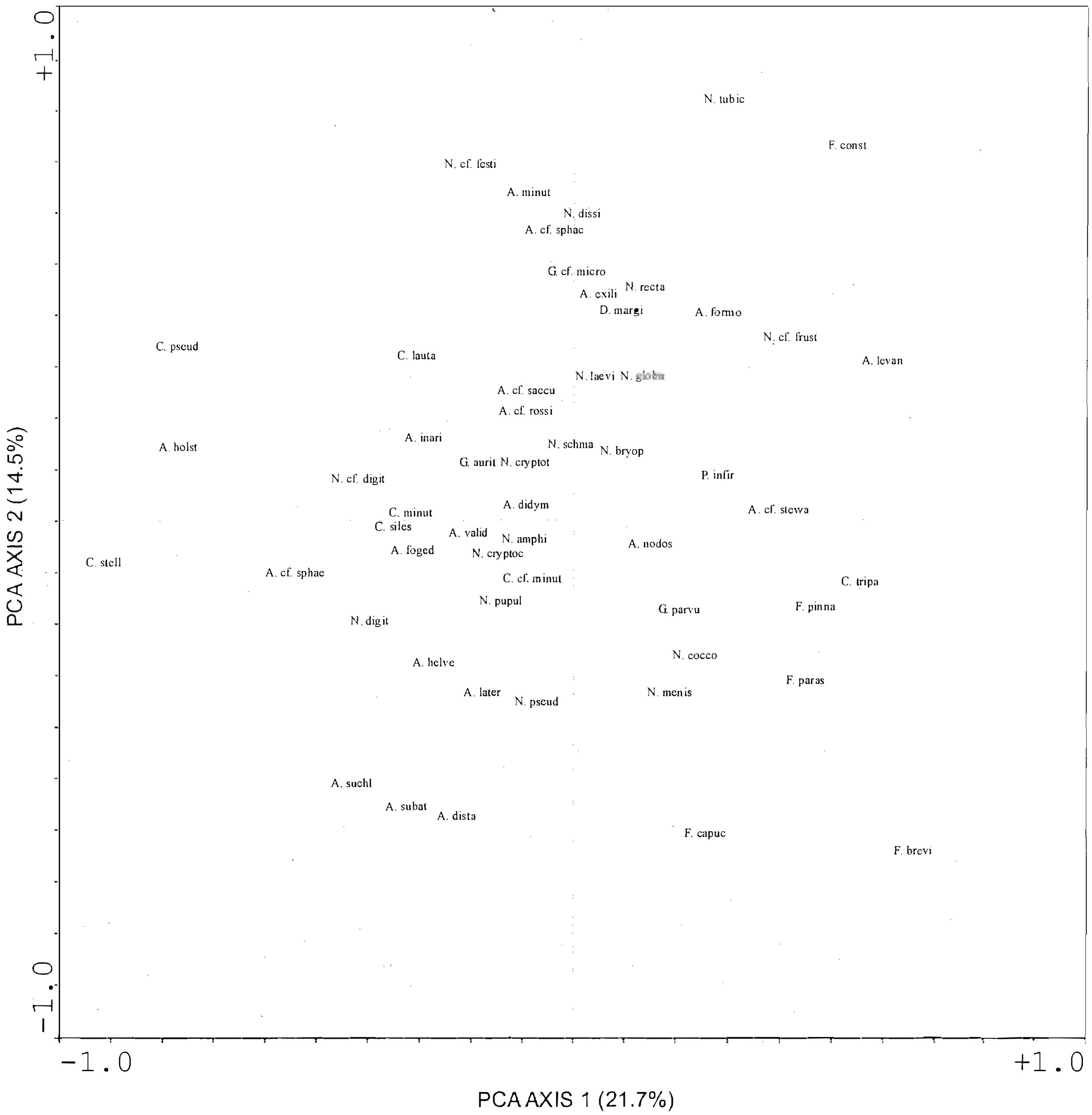

Figure 17. PCA ordination diagram for diatom species. The notation identifies the diatom taxa present in the sediments of Mirror Lake where species with similar environmental affinities occur closest to one another in the ordination. PCA Axis 1 explains 21.7% of the variance in the data set and PCA Axis 2 explains 14.5% of the variance in the data. The remaining 63.8% of the variance is explained by subsequent axes which are not shown.

Table 5. Summary of the results of the PCA analysis.					
Axes	1	2	3	4	Total Variance
Eigenvalues	0.217	0.145	0.067	0.057	1.000
Cumulative % variance of species data	21.7	36.2	42.9	48.6	
Sum of all unconstrained eigenvalues					1.000

proportion of the species variance, since diatoms often have very specific environmental tolerances. The environmental significance of these data was investigated with a diatom calibration set for the Cascade Mountain Ecoregion (Eilers et al. 1998).

Even though the Cascades calibration set (Eilers et al. 1998) is the closest geographical calibration set to the Mirror Lake area, ANALOG analysis shows very high dissimilarities between the fossil and modern data sets. The results of ANALOG analysis are included in Appendix E. Of all the diatom taxa from Mirror Lake discussed in this report, only 31% were also present in the calibration taxon list. A more accurate reconstruction would be obtained if a calibration set were developed for the Mirror Lake area.

The reconstructions for pH, TP and conductivity obtained from WACALIB analysis are shown in Figure 18. The data from these analyses are included in Appendix F. However, due to the poor analogue, these reconstructions should be considered as reflective of general trends, and not as absolute reconstructions. Table 6 outlines the errors obtained from the weighted averaging analysis for both the original data set and the bootstrapped data set (note that the analyses for Conductivity and TP were run with log-transformed data).

The RMSE values for each environmental parameter being reconstructed are shown as error bars on Figure 18.

Table 6. Root Mean Square Error (RMSE) for the WACALIB reconstructions.		
	RMSE	RMSE(boot)
pH	0.4458	0.586
TP	0.3808	0.519
Conductivity	0.2144	0.317

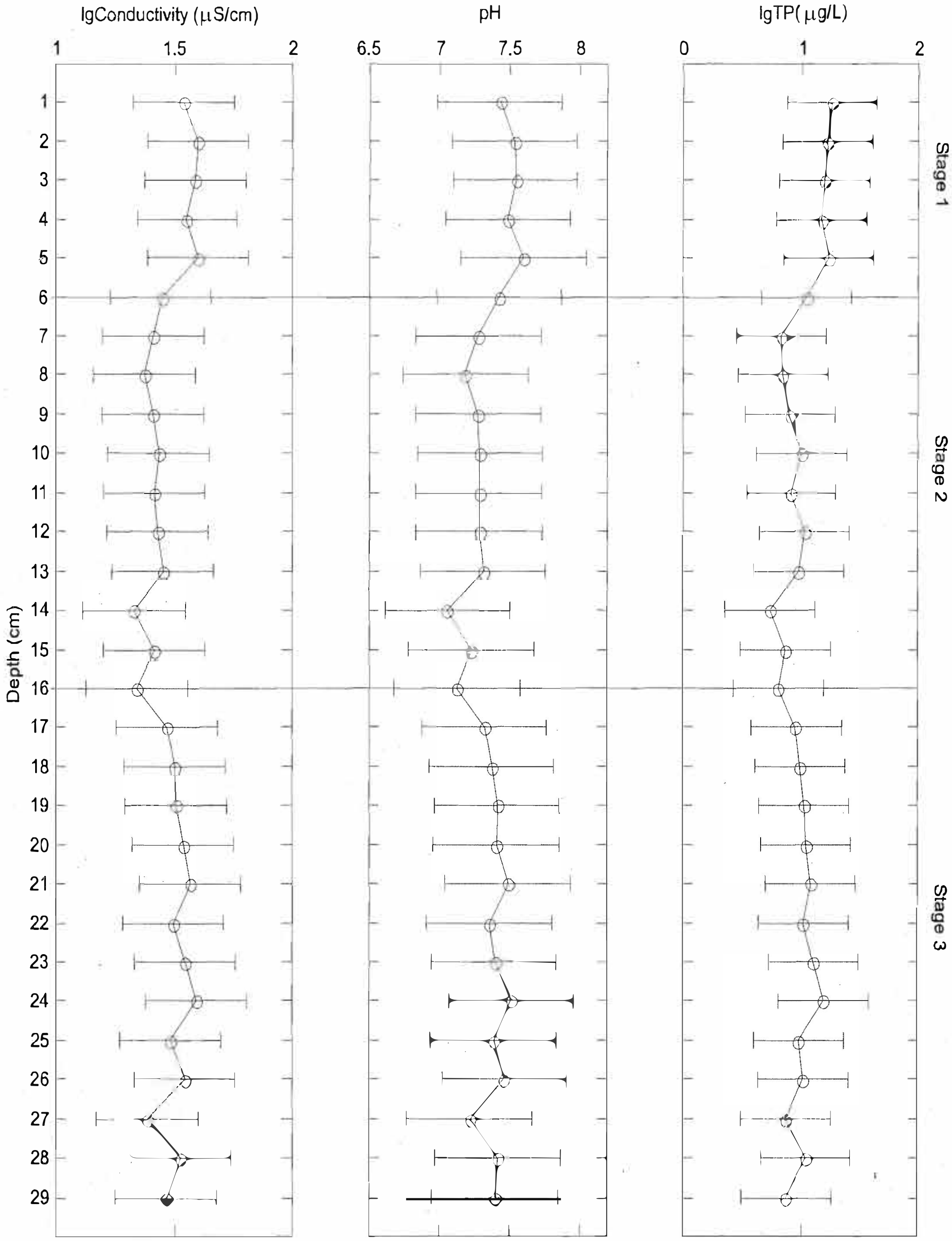

Figure 18. WACALIB modeled reconstructions of conductivity, pH, and total phosphorus (TP) based on a diatom calibration set for the Oregon/Washington Cascades. The model links water chemistry preferences for individual diatom taxa and summarizes the inferred water chemistry for each sediment interval. The uncertainty of the model reconstructions of lake chemistry are displayed as horizontal bars for each observation. The overlapping ranges on the uncertainty estimates indicate that the inferred changes in water chemistry for Mirror Lake are not statistically significant ($P < 0.05$).

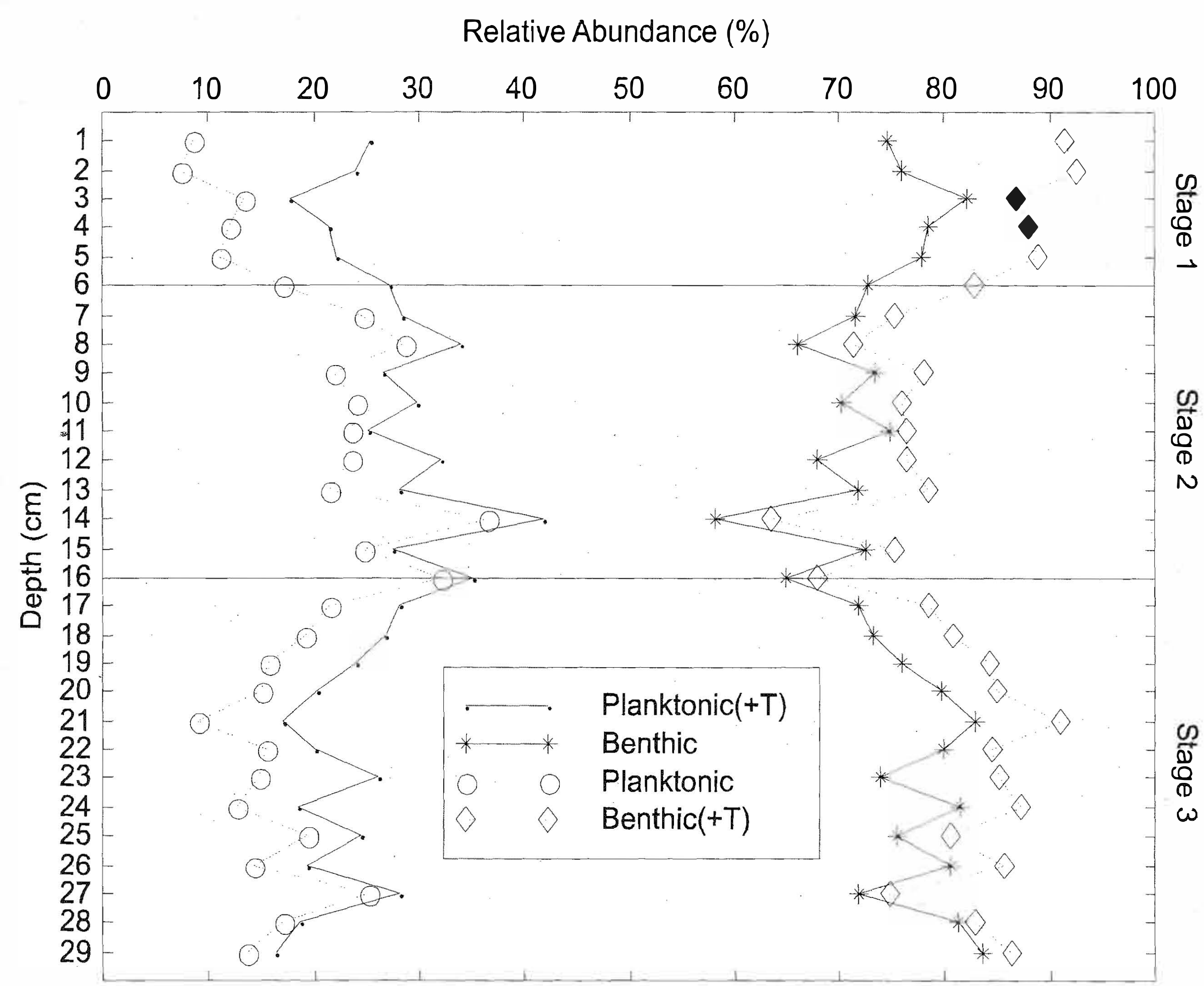

Figure 19. Ratio of planktonic:benthic diatoms in Mirror Lake sediments. The three stages are based on the zones in diatom community composition defined in the ordination process shown in Figure 16.

Throughout the core, benthic diatoms were more abundant than the planktonic diatoms. However, the ratio of planktonic:benthic was variable throughout the core. Depth intervals 7-8 cm, 13-14 cm, 15-16 cm and 26-27 cm indicate points at which the relative proportion of planktonic diatoms increased significantly relative to that of the benthic proportion. The different groupings of the tychoplanktonic diatoms did not affect this trend. Figure 19 shows the changes in the ratio of planktonic vs. benthic diatoms. The respective relative abundances at each depth interval for these two types of diatoms are included in Appendix G.

V. DISCUSSION

A. Lake Sensitivity to Atmospheric Deposition

The 15 lakes sampled in the Eagle Cap Wilderness in Fall 1998 are all moderately buffered systems with sufficient acid neutralizing capacity (ANC) to protect the lakes from modest stress from atmospheric deposition of acid precursors. The minimum ANC value of near 50 μeq/L corresponds to an upper limit of lake sensitivity to acidic deposition. Most of the lakes had ANC values well above this threshold. The weathering of base cations in the study area appears to be largely derived from congruent dissolution of carbonate-bearing rocks which provides the source of bicarbonate in the lakes. This is indicated by the strong linear relationship between ANC and base cations (Figure 20) and a much poorer fit for silica versus base cations (Figure 21). The presence of calcite or related minerals in the watersheds provides a virtually inexhaustible supply of neutralizing materials to protect against chronic acidification. The lakes show no anion deficit that would suggest loss of ANC by acidification or influence from organic anions (Figure 22).

The one caveat regarding lake sensitivity to acidic inputs is the issue of seasonality. Lakes with ANC in the range of 50 to 100 μeq/L may still be impacted on an episodic basis by large volumes of snowmelt runoff. Snowmelt typically has little opportunity to interact with underlying soils and bedrock and consequently the runoff can be acidic. For lakes with small volumes relative to the percentage of snowmelt input, the spring time chemistry can decline dramatically. Eilers et al. (1998) observed a decline in a Washington Cascade lake from an ANC of 90 μeq/L in fall to a minimum of 10 μeq/L in the spring. The period of minimum ANC in these high elevation lakes can be extremely short-lived, lasting only several days. Because the accumulated acids in a snowpack elutriate, the acidic snowmelt would normally precede the peak snowmelt event. Thus, a monitoring program designed to sample the period of greatest

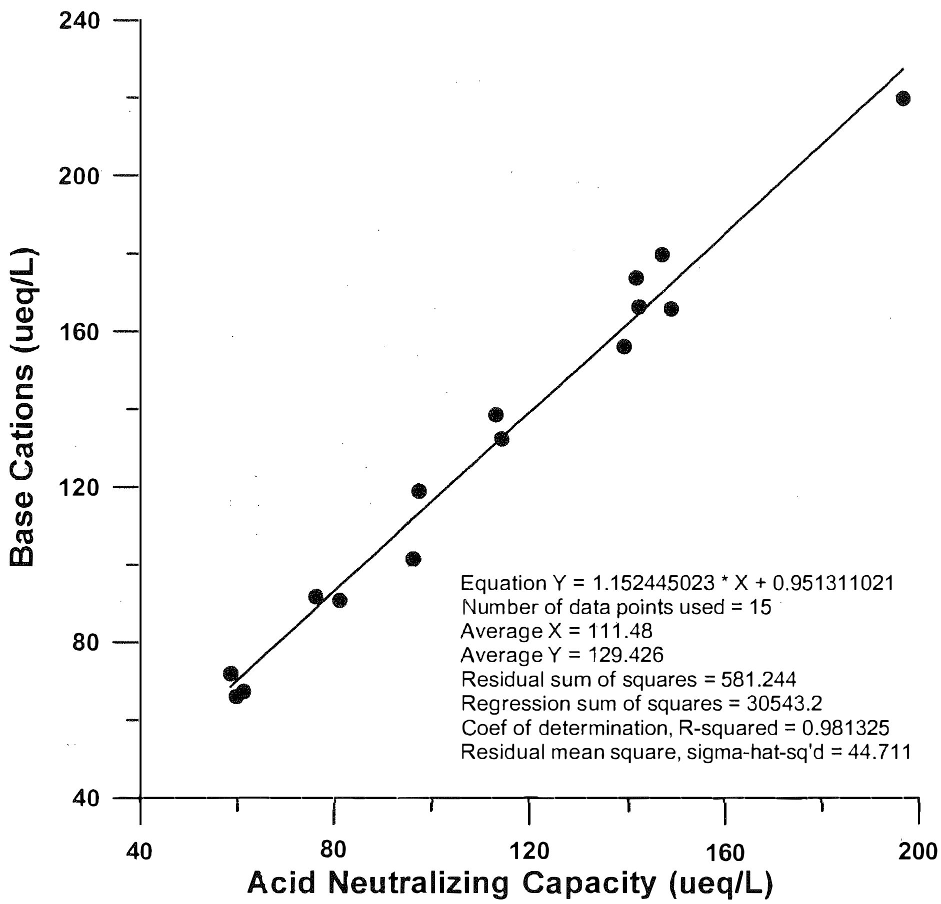

Figure 20. Concentrations of base cations versus ANC in Eagle Cap Wilderness lakes sampled in September 1998. A linear fit of the data is presented showing a coefficient of determination of 0.981.

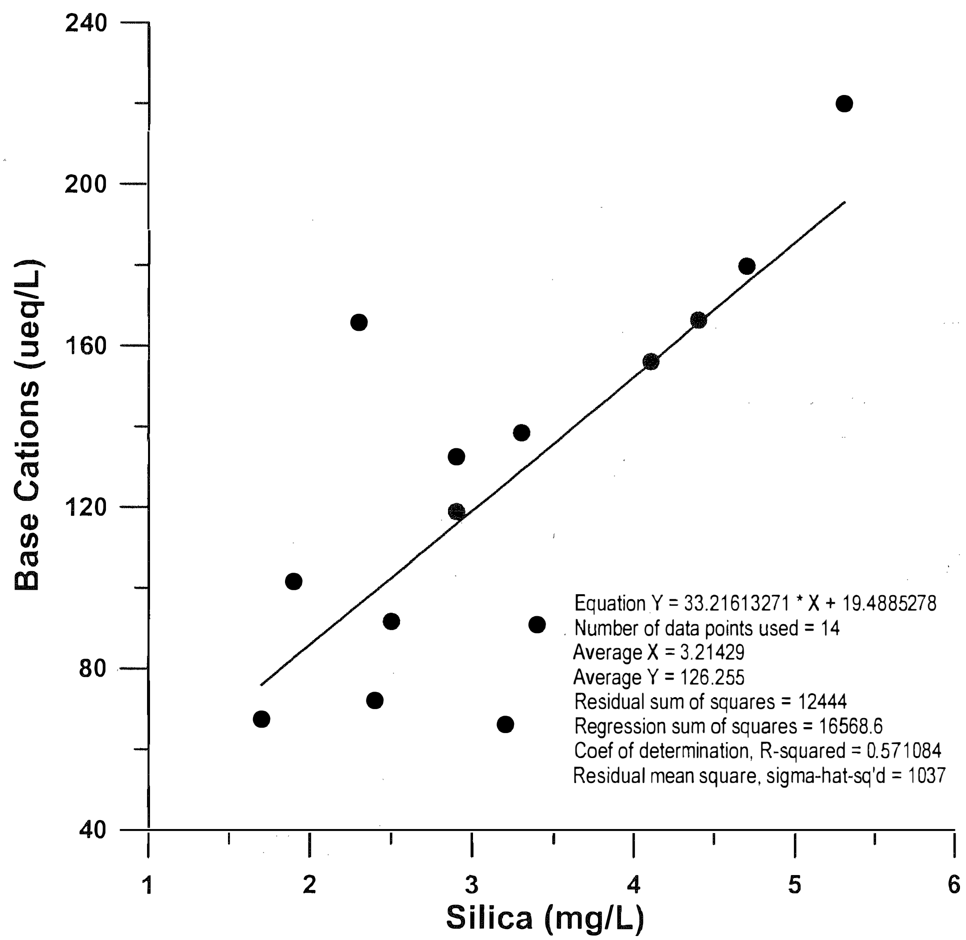

Figure 21. Concentrations of base cations versus silica in Eagle Cap Wilderness lakes sampled in September 1998. The linear fit of the data is presented showing a coefficient of determination of 0.571.

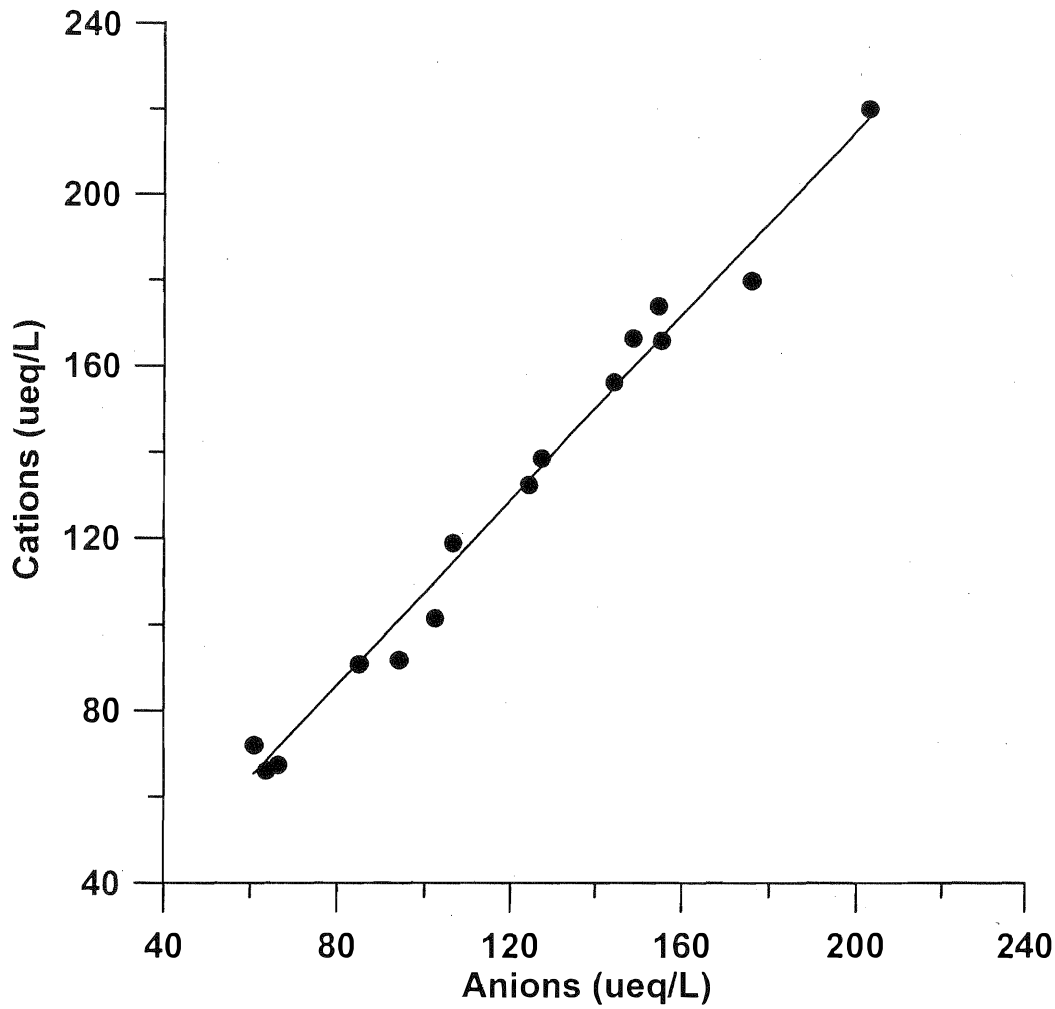

Figure 22. Sum of cations versus sum of anions in Eagle Cap Wilderness lakes.

impact from acidic snowmelt would need to be sampling when field access would be highly challenging.

The acid-base chemistry of the study lakes is fairly consistent among lakes. These are largely $Ca(HCO_3)_2$ systems with very low contributions of organic anions. A useful feature of these types of lakes is that the acid neutralizing capacity (ANC) is linearly related to the specific conductance (or conductivity) (Figure 23). Consequently, a relatively easy method of quickly assessing the acid-base status of wilderness lakes is field measurement of conductivity. The linear relationship between ANC and conductivity will hold until the ANC becomes negative

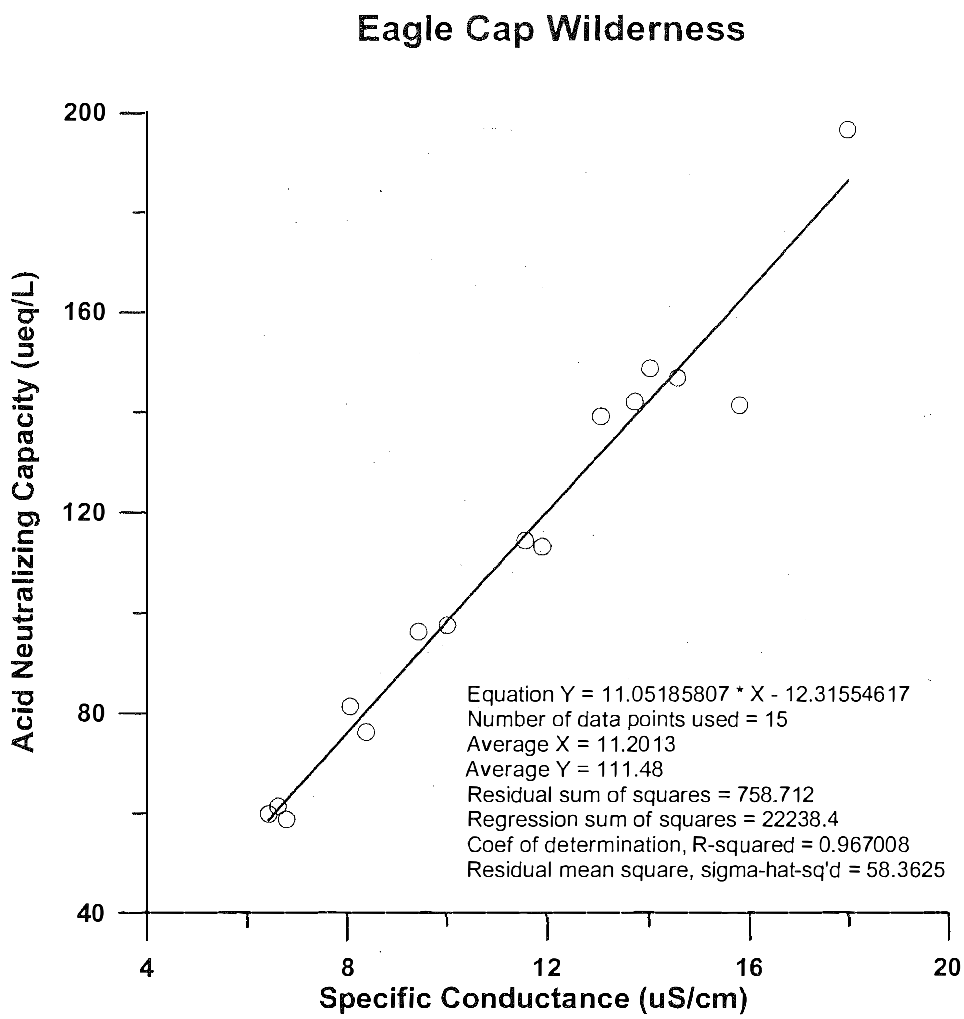

Figure 23. Measured ANC versus specific conductance in Eagle Cap Wilderness lakes sampled in September 1998. The linear fit of the data is presented showing a coefficient of determination of 0.967.

(i.e. ANC $-[H]^+ < 0$), which will result when acid anions exceed the base cations ($C_B - C_A < 0$; where $C_B = \Sigma$ base cations and $C_A = \Sigma$ acid anions). When ANC becomes negative (in waters relatively free of organic anions), the pH will drop below 5.6. Thus by using two simple field instruments, pH and conductivity (or using a multiparameter instrument), it is relatively easy to monitor the general acid-base status of these wilderness lakes.

The water chemistry and phytoplankton data presented here provide some level of characterization for the lakes, assuming that future comparisons are based on samples collected

during the fall period. As noted above, lake chemistry and biology are both transitional through the year and it is important that if future samples are collected for the purpose of comparing with these 1998 data, that they be done in a similar manner. Alternatively, additional samples from these lakes in spring and summer would provide a more complete "baseline" for comparison.

B. Lake Nutrient Status and Phytoplankton Assemblages

Nitrogen appears to be limiting or co-limiting primary production in most of the study lakes based on the low inorganic nitrogen concentrations relative to phosphorus concentrations. Phosphorus concentrations in 7 of 15 sample lakes were $\geq$ 10 µg/L which should be adequate to maintain moderate phytoplankton populations in the lakes. However, algal biovolume was only weakly correlated with TP (Figure 24), providing additional indication that P alone was not limiting primary production during the period of sampling. N-limitation appears to be relatively common among high elevation lakes in the western United States.

Sources of nitrogen in these cases are derived largely from atmospheric deposition. Factors that could increase the productivity of the lakes include increased nitrogen in the deposition and anthropogenic sources of nitrogen from terrestrial sources. Examples of increased nitrogen from atmospheric sources include emissions of N from combustion of fossil fuels (e.g., power plants and automobiles), combustion of plant materials (e.g., forest or range fires), and long-range transport of ammonia emissions from confined animal livestock operations. Examples of terrestrial sources of nitrogen include livestock excretion products, human waste products, and combustion of vegetation in the watershed. The latter activity provides nitrogen released from the combustion as well as loss of uptake of N caused by the removal of vegetation. Thus, the removal of vegetation in the watershed promotes enhanced export of N to the lake by releasing N stored in the plants and soils and reducing the uptake of N deposited from atmospheric and animal sources.

The high diversity of plankton assemblages among the study lakes is somewhat surprising given the overall similarity in water chemistry among the lakes. We presume that variation in physical habitat and possibly in unmeasured micronutrients, in part, contribute to the observed variation. Although cyanobacteria were moderately abundant in Craig Lake, the presence of *Anabaena planktonica* is not unusual in high quality lakes and is not sufficient evidence to conclude that the lake has been impacted in any way.

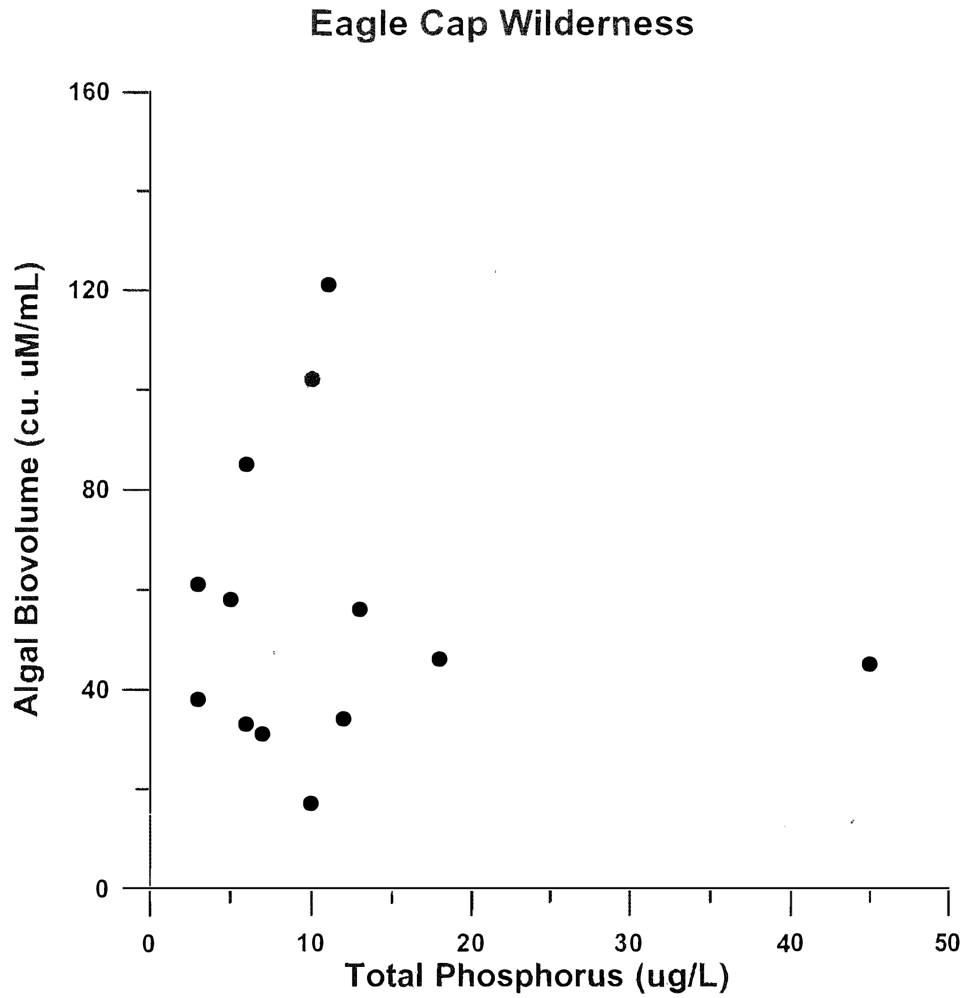

Figure 24. Algal biovolume versus total phosphorus concentrations in Eagle Cap Wilderness lakes sampled in September 1998. There is no apparent relationship for this group of lakes based on the September data.

C. Paleolimnology and Temporal Trends in Mirror Lake

Mirror Lake appeared to be reasonably typical of the sampled Eagle Cap lakes and thus provides an excellent "type" lake for assessing long-term trends in the wilderness. The sediment chemistry and diatom history appears to have been relatively stable, indicating that recent changes, if any, to the lake have been small. The calculated changes in lake pH, phosphorus, and conductivity were all statistically insignificant. Although the standard errors for these inferred changes were relatively large (because the diatom calibration set was derived from the Cascade

Range which had taxa different from the Wallowa Mountains), examination of the relative abundances of sediment diatoms in Mirror Lake showed few notable changes. Perhaps the most sensitive statistical analysis of the diatom assemblages was derived from the PCA analysis, which indicated three "stages" of diatom assemblages in the last 2000 years.

The diatom communities in the sediments from 0 to 6 cm (present to circa 1942) were distinct from those from 6 to 16 cm (~1942 to ~1800) and from 16 to 29 cm (~ 1800 to year 50). The sediments in the Stage II group were notable for higher relative abundances of *Cyclotella* and lower abundances of *Fragillaria brevistriata* and *F. construens* var. *venter*. Charcoal abundances for several size classes also differed slightly and silicates were higher than in the other two stages. Some notable features of the Stage I sediments include higher abundances of *F. construens*, greater frequency of charcoal in the 50-75 μM size class, and very low silicates. The changes in the upper portion of the core are consistent with anthropogenic influences, since *F. construens* is often found in assemblages with increasing nutrient levels and the greater charcoal could reflect inputs from campfires. However, other factors could also cause these changes and without a more distinct signal, we are reluctant to associate the changes observed in the recent sediments to a specific cause or causes at this time.

The sediment dating of Mirror Lake raises some interesting questions regarding the SAR in the lake. The dating of the lower portions of the sediment using ^{14}C suggest a SAR much lower than was measured in the upper sediments using ^{210}Pb techniques. If we accept the dating measurements as accurate, the results show that there has been a dramatic increase in the SAR in the last 100 to 150 years. The dating of the upper sediments shows a declining SAR which is consistent with a major increase in SAR occurring in the previous century. Restated, the lake appears to be in a period of recovery from a relatively short-term increase in SAR. There is no extraordinarily large increase in charcoal during the previous century that suggests a relationship between fire and a high rate of watershed erosion. Neither is there a dramatic change in the diatoms that would indicate a major change in water quality. One possible explanation for the apparently high SAR in the last century is that watershed erosion greatly increased with the first use of the area for summer grazing. The fragile subalpine/alpine meadows would have been susceptible to disturbance from these activities and likely would have eroded. The difficulty in accurately dating these activities is a function of the poor resolution of both ^{210}Pb and ^{14}C dating in that range.

The charcoal data show a continuous input of charcoal to the system. Although there are minor variations in the charcoal record, the overall impression is one of frequent inputs. The high proportion of small size (25-50 μm) charcoal suggests that the majority of charcoal to the lake is derived from fairly long-range (outside the watershed) transport. The regular input of charcoal to the lake sediments indicates that fire frequency in the region is relatively high and its presence throughout the core is evidence that fire is a regular feature of the landscape. When the decrease in SAR (from present to 1942) is combined with a fairly consistent charcoal concentration in the same period, it indicates that the mass of charcoal input to the lake has actually declined in the last 60 years. This would be consistent with fire suppression activities which have effectively reduced the magnitude of large-scale forest fires in many areas of the West.

In summary, most of the paleolimnology data show that only minor changes have occurred in Mirror Lake over the last 2000 years. The diatom and sediment chemistry show evidence of three recognizable stages, the most recent occurring in the last 60 years. Although the diatom assemblage has shifted, the magnitude of the change is relatively small. The charcoal record in the sediment indicates a fairly stable input of fine material, probably derived from moderate to long-range transport of combustion products. The major anomaly in the sediment is the disparate rates of sediment accumulation calculated using ^{210}Po and ^{14}C. The upper 15 cm of sediments dated using ^{210}Po show a comparatively rapid SAR, although the rates in the top 6 cm of sediment are nearly 50% less than those calculated for the intervals from 7 to 10 cm. One possible explanation for the sediment dating results is that a major watershed disturbance occurred mid-core (~ 15 cm) corresponding to sometime during the 1800's. We do not know the nature of this disturbance, assuming the dating is accurate, but the results are consistent with an activity such as early grazing. Subsequent investigations would be required to test this hypothesis.

Acknowledgments

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conducted much of the field sampling. The University of Toronto, Department of Geology, provided laboratory support for T. Samman in conducting the paleolimnological analyses of Mirror Lake.

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VII. APPENDICES

A. Analytical results and quality assurance review
B. Phytoplankton community composition
C. Plates of charcoal and diatom particles
D. Diatom relative abundances
E. ANALOG analysis
F. WACALIB Reconstruction Data
G. Planktonic:Benthic ratio of diatoms

APPENDIX A

Analytical Results and Quality Assurance Review

SAMPLE LOG #130

CLIENT/PROJECT: E&S - EAGLE CAP
DATE REC'D AA: SEP 29, 1998

LAB NO.	DATE	IDENTIFICATION	PARAMETER	RESULT	UNITS
	22-Sep-98	MIR 01	TP	0.010	mg P/L
			SiO2	2.9	mg/L
	23-Sep-98	HOR 01	TP	0.006	mg P/L
			SiO2	4.1	mg/L
	23-Sep-98	BEN 01	TP	0.010	mg P/L
			SiO2	3.2	mg/L
	23-Sep-98	CRA 01	TP	0.011	mg P/L
			SiO2	2.4	mg/L
	23-Sep-98	BLU 01	TP	0.003	mg P/L
			SiO2	2.5	mg/L
	23-Sep-98	MIN 01	TP	0.003	mg P/L
			SiO2	3.3	mg/L
	23-Sep-98	RAZ 01	TP	0.005	mg P/L
			SiO2	3.4	mg/L
	23-Sep-98	LEE 01	TP	0.003	mg P/L
			SiO2	4.4	mg/L
	23-Sep-98	DOU 01	TP	0.006	mg P/L
			SiO2	2.3	mg/L
	24-Sep-98	GLA 01	TP	0.007	mg P/L
			SiO2	1.9	mg/L
	24-Sep-98	MOC 01	TP	0.013	mg P/L
			SiO2	2.9	mg/L
	24-Sep-98	MOC 02	TP	0.016	mg P/L
			SiO2	2.8	mg/L
	24-Sep-98	SUN 01	TP	0.012	mg P/L
			SiO2	4.7	mg/L
	24-Sep-98	SNO 02	TP	0.014	mg P/L
			SiO2	4.8	mg/L
	24-Sep-98	PRO 01	TP	0.018	mg P/L
			SiO2	1.7	mg/L
	27-Sep-98	CRE 01	TP	0.045	mg P/L
			SiO2	5.3	mg/L

SAMPLE ID	pH	uS/cm Conduct.	pH	CA	MG	NA	K	UEQ/L NH4	CL	NO3	SO4	[ANC]	SUM ANIONS	SUM CATIONS
MIR-01	6.859	11.550	0.14	84.279	8.915	26.923	10.247	1.866	1.379	0.000	8.540	114.3	124.2	132.4
BLU-01	6.706	8.370	0.20	57.245	5.172	23.607	3.755	1.866	10.232	0.000	7.635	76.2	94.1	91.8
BEN-01	6.659	6.410	0.22	29.382	6.075	18.693	10.247	1.496	1.733	0.000	2.202	59.8	63.7	66.1
CRA-01	6.611	6.770	0.24	38.655	7.001	22.326	1.757	2.052	2.215	0.000	0.000	58.7	60.9	72.0
CRE-01	7.073	17.960	0.08	155.444	17.220	37.404	7.477	2.237	1.693	0.000	4.484	196.5	202.7	219.9
DOU-01	6.981	13.990	0.10	109.347	11.920	32.884	9.687	1.866	1.867	0.000	4.622	148.6	155.1	165.8
HOR-01	6.799	13.020	0.16	106.992	10.902	28.034	8.576	1.496	1.776	0.000	3.342	139.0	144.1	156.2
LEE-01	6.965	13.690	0.11	108.168	16.675	31.012	8.576	1.866	1.877	0.000	4.656	141.9	148.4	166.4
MIN-01	6.782	11.880	0.17	84.279	17.220	29.521	5.855	1.496	1.526	0.000	12.571	113.1	127.2	138.5
RAZ-01	6.825	8.040	0.15	55.293	7.001	19.959	6.933	1.496	1.628	0.000	2.088	81.2	84.9	90.8
UPP-01	6.818	15.790	0.15	93.177	14.000	51.172	13.085	2.237	4.136	0.000	8.937	141.3	154.4	173.8
GLA-01	6.833	9.420	0.15	67.285	6.075	15.285	10.810	1.866	0.968	0.000	5.103	96.2	102.3	101.5
MOC-01	6.743	10.000	0.18	75.645	7.948	23.974	9.687	1.496	1.698	0.000	7.337	97.4	106.4	118.9
PRO-01	6.669	6.600	0.21	44.009	4.296	12.455	5.323	1.124	1.315	0.000	3.884	61.3	66.5	67.4
SUN-01	6.903	14.530	0.13	116.501	8.915	38.919	13.085	2.237	3.170	0.000	26.002	146.7	175.9	179.8

SAMPLE ID	pH	uS/cm Conduct.	--------- pH	--------- CA	--------- MG	--------- NA	--------- K	UEQ/L NH4	--------- CL	--------- NO3	--------- SO4	--------- [ANC]	SUM ANIONS	SUM CATIONS
MIR-01	6.859	11.550	0.14	84.279	8.915	26.923	10.247	1.866	1.379	0.000	8.540	114.3	124.2	132.4
BLU-01	6.706	8.370	0.20	57.245	5.172	23.607	3.755	1.866	10.232	0.000	7.635	76.2	94.1	91.8
BEN-01	6.659	6.410	0.22	29.382	6.075	18.693	10.247	1.496	1.733	0.000	2.202	59.8	63.7	66.1
CRA-01	6.611	6.770	0.24	38.655	7.001	22.326	1.757	2.052	2.215	0.000	0.000	58.7	60.9	72.0
CRE-01	7.073	17.960	0.08	155.444	17.220	37.404	7.477	2.237	1.693	0.000	4.484	196.5	202.7	219.9
DOU-01	6.981	13.990	0.10	109.347	11.920	32.884	9.687	1.866	1.867	0.000	4.622	148.6	155.1	165.8
HOR-01	6.799	13.020	0.16	106.992	10.902	28.034	8.576	1.496	1.776	0.000	3.342	139.0	144.1	156.2
LEE-01	6.965	13.690	0.11	108.168	16.675	31.012	8.576	1.866	1.877	0.000	4.656	141.9	148.4	166.4
MIN-01	6.782	11.880	0.17	84.279	17.220	29.521	5.855	1.496	1.526	0.000	12.571	113.1	127.2	138.5
RAZ-01	6.825	8.040	0.15	55.293	7.001	19.959	6.933	1.496	1.628	0.000	2.088	81.2	84.9	90.8
UPP-01	6.818	15.790	0.15	93.177	14.000	51.172	13.085	2.237	4.136	0.000	8.937	141.3	154.4	173.8
GLA-01	6.833	9.420	0.15	67.285	6.075	15.285	10.810	1.866	0.968	0.000	5.103	96.2	102.3	101.5
MOC-01	6.743	10.000	0.18	75.645	7.948	23.974	9.687	1.496	1.698	0.000	7.337	97.4	106.4	118.9
PRO-01	6.669	6.600	0.21	44.009	4.296	12.455	5.323	1.124	1.315	0.000	3.884	61.3	66.5	67.4
SUN-01	6.903	14.530	0.13	116.501	8.915	38.919	13.085	2.237	3.170	0.000	26.002	146.7	175.9	179.8

QA/QC Section:

SAMPLE ID	TOTAL ION	%ION DIFF	SUM BASES	SUM ACIDS	DIFF= ALK	ANC	FLAG %ION	% COND DIFF	FLAG % COND	THEOR. COND	TP	SiO2	Biovolume
MIR-01	256.6	-3.2	130.4	9.9	120.4	114.3	OK	10.25	OK	12.73	10	2.9	102
BLU-01	185.9	1.2	89.8	17.9	71.9	76.2	OK	13.40	OK	9.49	3	2.5	38
BEN-01	129.8	-1.8	64.4	3.9	60.5	59.8	OK	2.12	OK	6.55	10	3.2	17
CRA-01	133.0	-8.4	69.7	2.2	67.5	58.7	OK	-3.68	OK	6.52	11	2.4	121
CRE-01	422.5	-4.1	217.5	6.2	211.4	196.5	OK	13.94	OK	20.46	45	5.3	45
DOU-01	320.9	-3.3	163.8	6.5	157.3	148.6	OK	12.02	OK	15.67	6	2.3	85
HOR-01	300.3	-4.0	154.5	5.1	149.4	139	OK	12.59	OK	14.66	6	4.1	33
LEE-01	314.8	-5.7	164.4	6.5	157.9	141.9	OK	12.29	OK	15.37	3	4.4	38
MIN-01	265.7	-4.3	136.9	14.1	122.8	113.1	OK	10.77	OK	13.16	3	3.3	61
RAZ-01	175.7	-3.4	89.2	3.7	85.5	81.2	OK	7.62	OK	8.65	5	3.4	58
UPP-01	328.2	-5.9	171.4	13.1	158.4	141.3	OK	3.05	OK	16.27			
GLA-01	203.7	0.4	99.5	6.1	93.4	96.2	OK	7.52	OK	10.13	7	1.9	31
MOC-01	225.4	-5.5	117.3	9.0	108.2	97.4	OK	12.45	OK	11.24	13	2.9	56
PRO-01	133.9	-0.7	66.1	5.2	60.9	61.3	OK	1.33	OK	6.69	18	1.7	46
SUN-01	355.7	-1.1	177.4	29.2	148.2	146.7	OK	23.96	OK	18.01	12	4.7	34

APPENDIX B

Phytoplankton Community Composition

Slide #	Lake Sp name	Station Sp code	Date cells/col	Pplk Dens	Diversity % Dens	TSI-B Biovol	Tot Dens % Biovol	Tot Biovol	# spp
EM62	Upper Razz Lake	BEN01	98-09-23	PPLK	0.3620126	21	715.4963	17243.12	5
	Rhodomonas minuta	RDMN	1	678.1955	94.78673	13563.91	78.66273		
	Ankistrodesmus falcatus	AKFL	1	27.12782	3.791469	678.1955	3.933136		
	Cryptomonas erosa	CXER	1	3.390977	0.4739336	1763.308	10.22615		
	Scenedesmus quadricauda	SCQD	4	3.390977	0.4739336	881.6541	5.113077		
	Sphaerocystis schroeteri	SFSR	3	3.390977	0.4739336	356.0526	2.064897		
EM63	Blue Lake	BLU01	98-09-23	PPLK	0.3497361	26.4	1345.572	37941.3	9
	Selenastrum minutum	SLMN	1	1288.268	95.74134	25765.36	67.90849		
	Ankistrodesmus falcatus	AKFL	1	27.59059	2.050473	689.7647	1.817979		
	Unidentified flagellate	MXFG	1	10.61176	0.7886437	212.2353	0.559378		
	Cymbella minuta	CMMN	1	8.489411	0.6309149	3141.082	8.278794		
	Frustulia rhomboides	FSRH	1	2.122353	0.1577287	2292.141	6.041282		
	Cymbella affinis	CMAF	1	2.122353	0.1577287	3820.235	10.0688		
	Cymbella sinuata	CMSN	1	2.122353	0.1577287	2.97E+02	0.7831292		
	Fragilaria construens	FRCN	1	2.122353	0.1577287	237.7035	0.6265033		
	Glenodinium sp.	GDXX	1	2.122353	0.1577287	1485.647	3.915646		
EM64	Craig Lake	CRA01	98-09-23	PPLK	2.354206	34.7	740.9288	121364.1	14
	Crucigenia quadrata	CGQD	1.4	393.0143	53.04346	46768.7	38.53586		
	Selenastrum minutum	SLMN	1.3	141.7429	19.13043	3685.314	3.036577		
	Oocystis pusilla	OCPU	3	38.65714	5.21739	6262.457	5.160058		
	Ankistrodesmus falcatus	AKFL	1	38.65714	5.21739	966.4286	0.7963052		
	Chromulina sp.	KMXX	1	32.21429	4.347825	644.2858	0.5308701		
	Sphaerocystis schroeteri	SFSR	7	25.77143	3.47826	6314	5.202527		
	Oocystis lacustris	OCLA	2	12.88571	1.73913	7937.6	6.54032		
	Chroococcus minimus	CKMN	2	12.88571	1.73913	360.8	0.2972873		
	Glenodinium sp.	GDXX	1	12.88571	1.73913	9020	7.432182		
	Unidentified flagellate	MXFG	1	6.442857	0.869565	128.8571	0.106174		
	Scenedesmus quadricauda	SCQD	4	6.442857	0.869565	1675.143	1.380262		
	Gomphonema subclavatum	GFSB	1	6.442857	0.869565	3865.714	3.185221		
	Cosmarium sp.	CSXX	1	6.442857	0.869565	1353	1.114827		

Slide #	Lake / Sp name	Station / Sp code	Date / cells/col	Pplk / Dens	Diversity / % Dens	TSI-B / Biovol	Tot Dens / % Biovol	Tot Biovol	# spp
	Anabaena planctonica	ABPL	1	6.442857	0.869565	32381.8	26.68153		
EM65	Crescent Lake	CRE01	98-09-23	PPLK	1.77055	2.76E+01	478.938	44700.88	6
	Rhodomonas minuta	RDMN	1	271.3982	56.66666	5.43E+03	12.14286		
	Chromulina sp.	KMXX	1	103.7699	21.66667	2075.398	4.642857		
	Cryptomonas erosa	CXER	1	59.86726	12.5	31130.97	69.64286		
	Unidentified flagellate	MXFG	1	19.95575	4.166667	399.115	0.8928571		
	Ankistrodesmus falcatus	AKFL	3	15.9646	3.333333	1197.345	2.678571		
	Sphaerocystis schroeteri	SFSR	16	7.982301	1.666667	4470.088	10		
EM66	Crescent Lake	CRE01	98-09-23	PPLK	1.77055	27.6	478.938	44700.88	6
	Rhodomonas minuta	RDMN	1	271.3982	56.66666	5427.964	12.14286		
	Chromulina sp.	KMXX	1	103.7699	21.66667	2075.398	4.642857		
	Cryptomonas erosa	CXER	1	59.86726	12.5	31130.97	69.64286		
	Unidentified flagellate	MXFG	1	19.95575	4.166667	399.115	0.8928571		
	Ankistrodesmus falcatus	AKFL	3	15.9646	3.333333	1197.345	2.678571		
	Sphaerocystis schroeteri	SFSR	16	7.982301	1.666667	4470.088	10		
EM67	Glacier Lake	GLA01	98-09-24	PPLK	0.7041789	25	1271.82	31067.89	7
	Selenastrum minutum	SLMN	1	1127.5	88.65247	2.26E+04	72.58298		
	Ankistrodesmus falcatus	AKFL	2	81.18	6.382978	4059	13.06494		
	Unidentified flagellate	MXFG	1	33.07333	2.600472	661.4667	2.129101		
	Rhodomonas minuta	RDMN	1	21.04667	1.654846	4.21E+02	1.354882		
	Dinobryon sertularia	DBST	1	3.006667	0.2364066	357.7933	1.15165		
	Synedra rumpens	SNRM	1	3.006667	0.2364066	420.9333	1.354882		
	Oocystis pusilla	OCPU	16	3.006667	0.2364066	2597.76	8.36156		
EM68	Horseshoe Lake	HOR01	98-09-23	PPLK	2.300787	25.4	316.4912	32709.37	15
	Chromulina sp.	KMXX	1	184.6199	58.33334	3692.398	11.2885		
	Chroococcus minimus	CKMN	6.5	39.56141	12.5	3600.088	11.00629		

Slide #	Lake Sp name	Station Sp code	Date cells/col	Pplk Dens	Diversity % Dens	TSI-B Biovol	Tot Dens % Biovol	Tot Biovol	# spp
	Melosira distans alpigena	MLDA	2	26.37427	8.333334	11868.42	36.28447		
	Ankistrodesmus falcatus	AKFL	1.8	13.18713	4.166667	593.421	1.814224		
	Dinobryon sertularia	DBST	1	7.912281	2.5	941.5614	2.878568		
	Anacystis marina	ANMR	1	7.912281	2.5	2373.684	7.26E+00		
	Glenodinium sp.	GDXX	1	7.912281	2.5	5538.596	16.93275		
	Quadrigula closterioides	QDCL	8	5.274854	1.666667	1012.772	3.096275		
	Rhodomonas minuta	RDMN	1	5.274854	1.666667	105.4971	0.3225286		
	Pseudopedinella sp.	PZXX	1	5.274854	1.666667	791.228	2.418965		
	Unidentified flagellate	MXFG	1	2.637427	0.8333334	52.74854	0.1612643		
	Fragilaria construens	FRCN	3	2.637427	0.8333334	886.1754	2.70924		
	Hemidinium sp.	HDXX	1	2.637427	0.8333334	791.228	2.418965		
	Achnanthes minutissima	ACMN	1	2.637427	0.8333334	131.8713	0.4031608		
	Cyclotella ocellata	CCOC	1	2.637427	0.8333334	3.30E+02	1.007902		
EM69	Lee Lake	LEE01	98-09-23	PPLK	1.488169	26.5	370.0512	38141.71	10
	Chromulina sp.	KMXX	1	274.2344	74.10715	5484.688	14.37977		
	Melosira distans alpigena	MLDA	2	39.64835	10.71429	17841.76	46.77755		
	Ankistrodesmus falcatus	AKFL	1.2	16.52015	4.464286	495.6044	1.299377		
	Unidentified flagellate	MXFG	1	13.21612	3.571429	264.3223	0.6930008		
	Glenodinium sp.	GDXX	1	6.608058	1.785715	4625.641	12.12751		
	Dinobryon sertularia	DBST	6	6.608058	1.785715	4718.154	12.37006		
	Chroococcus minimus	CKMN	8	3.304029	0.8928573	370.0513	0.9702011		
	Hemidinium sp.	HDXX	1	3.304029	0.8928573	991.2087	2.598753		
	Pseudopedinella sp.	PZXX	1	3.304029	0.8928573	495.6044	1.299376		
	Oocystis pusilla	OCPU	16	3.304029	0.8928573	2854.681	7.48E+00		
EM70	Minam Lake	MIN01	98-09-23	PPLK	3.661564	29.7	319.8581	60664.3	25
	Rhodomonas minuta	RDMN	1	99.15603	31.00001	1983.121	3.269007		
	Chromulina sp.	KMXX	1	38.38298	12	767.6596	1.265422		
	Ankistrodesmus falcatus	AKFL	2.3	38.38298	12	2.21E+03	3.638089		
	Sphaerocystis schroeteri	SFSR	16	19.19149	6.000002	10747.23	17.71591		
	Cryptomonas erosa	CXER	1	15.99291	5.000001	8316.312	13.70874		

Slide #	Lake Sp name	Station Sp code	Date cells/col	Pplk Dens	Diversity % Dens	TSI-B Biovol	Tot Dens % Biovol	Tot Biovol	# spp
	Cymbella minuta	CMMN	1	12.79433	4.000001	4733.9	7.803436		
	Nitzschia capitellata	NZCP	1	9.595745	3.000001	3454.468	5.6944		
	Chlamydomonas sp.	CHXX	1	9.595745	3.000001	3118.617	5.140778		
	Unidentified flagellate	MXFG	1	6.397163	2	127.9433	0.2109037		
	Oocystis pusilla	OCPU	3	6.397163	2	1036.34	1.70832		
	Cymbella microcephala	CMMC	1	6.397163	2	339.0496	0.5588948		
	Anabaena flos-aquae	ABFA	1	6.397163	2	6397.163	10.54519		
	Anomoeoneis serians	AOSR	1	6.397163	2	1919.149	3.163555		
	Mallomonas sp.	MMXX	1	6.397163	2	2430.922	4.00717		
	Nitzschia frustulum	NZFR	1	6.397163	2	767.6595	1.265422		
	Diatomella balfouriana	DLBL	1	3.198581	1	959.5745	1.581778		
	Staurastrum sp.	SMXX	1	3.198581	1	767.6595	1.27E+00		
	Navicula cryptocephala veneta	NVCV	1	3.198581	1	303.8652	5.01E-01		
	Ulothrix sp.	ULXX	3	3.198581	1	767.6595	1.265422		
	Oocystis lacustris	OCLA	3	3.198581	1	2955.489	4.871875		
	Synedra rumpens	SNRM	1	3.198581	1	447.8014	0.7381629		
	Frustulia rhomboides	FSRH	1	3.198581	1	3454.468	5.6944		
	Mallomonas sp.	MMXX	1	3.198581	1	1215.461	2.003585		
	Quadrigula closterioides	QDCL	8	3.198581	1	614.1276	1.012338		
	Scenedesmus quadricauda	SCQD	4	3.198581	1	831.6312	1.370874		
EM71	Mirror Lake	MIR01	98-09-22	PPLK	2.195635	33.4	275.6375	101539.2	11
	Oocystis pusilla	OCPU	10	130.6902	47.41379	70572.71	69.50294		
	Sphaerocystis schroeteri	SFSR	9	66.5332	24.13793	20957.96	20.64027		
	Ankistrodesmus falcatus	AKFL	1	38.01897	13.7931	950.4742	0.9360666		
	Mallomonas sp.	MMXX	1	14.25711	5.172413	5417.703	5.335579		
	Rhodomonas minuta	RDMN	1	7.128556	2.586207	142.5711	0.14041		
	Dinobryon sertularia	DBST	1.5	4.752371	1.724138	848.2982	0.8354394		
	Cyclotella ocellata	CCOC	1	4.752371	1.724138	594.0463	0.5850416		
	Chromulina sp.	KMXX	1	2.376185	0.8620688	47.52371	4.68E-02		
	Melosira excurrens	MLEX	1	2.376185	0.8620688	522.7608	0.5148366		
	Crucigenia quadrata	CGQD	3	2.376185	0.8620688	605.9273	0.5967425		
	Cymbella minuta	CMMN	1	2.376185	0.8620688	879.1886	0.8658616		

Slide #	Lake Sp name	Station Sp code	Date cells/col	Pplk Dens	Diversity % Dens	TSI-B Biovol	Tot Dens % Biovol	Tot Biovol	# spp
EM72	Moccasin Lake	MOC01	98-09-24	PPLK	3.152194	29.2	238.4869	56457.66	16
	Chromulina sp.	KMXX	1	68.47644	28.71288	1369.529	2.425763		
	Mallomonas sp.	MMXX	1	51.94764	21.78218	19740.1	34.96444		
	Rhodomonas minuta	RDMN	1	23.61257	9.900991	472.2513	0.8364699		
	Ankistrodesmus falcatus	AKFL	1	18.89005	7.920794	472.2513	0.8364699		
	Oocystis pusilla	OCPU	8	16.5288	6.930694	7140.439	12.64742		
	Sphaerocystis schroeteri	SFSR	16	14.16754	5.940595	7933.822	14.0527		
	Selenastrum minutum	SLMN	1	9.445026	3.960397	188.9005	0.334588		
	Unidentified flagellate	MXFG	1	9.445026	3.960397	188.9005	0.334588		
	Cyclotella ocellata	CCOC	1	7.08377	2.970298	885.4713	1.568381		
	Dinobryon sertularia	DBST	8.5	4.722513	1.980198	4776.822	8.460894		
	Hannaea arcus	HNAR	1	2.361257	0.9900992	4132.199	7.319112		
	Gymnodinium sp.	GNXX	1	2.361257	0.9900992	6375.393	11.29234		
	Achnanthes linearis	ACLN	1	2.361257	0.9900992	311.6859	0.5520702		
	Achnanthes minutissima	ACMN	1	2.361257	0.9900992	118.0628	0.2091175		
	Oocystis lacustris	OCLA	2	2.361257	0.9900992	1454.534	2.576327		
	Mallomonas sp.	MMXX	1	2.361257	0.9900992	897.2775	1.589293		
EM73	Moccasin Lake	MOC02	98-09-24	PPLK	3.011601	28.4	257.0918	49899.77	15
	Chromulina sp.	KMXX	1	80.61353	31.35593	1612.271	3.231018		
	Mallomonas sp.	MMXX	1	43.57488	16.94915	16558.45	33.18342		
	Rhodomonas minuta	RDMN	1	32.68116	12.71187	653.6232	1.309872		
	Ankistrodesmus falcatus	AKFL	1	32.68116	12.71187	817.029	1.63734		
	Selenastrum minutum	SLMN	1	17.42995	6.779662	348.5991	0.6985985		
	Sphaerocystis schroeteri	SFSR	16	15.25121	5.932204	8540.676	17.11566		
	Unidentified flagellate	MXFG	1	8.714976	3.389831	174.2995	0.3492993		
	Hemidinium sp.	HDXX	1	6.536232	2.542373	1960.87	3.929616		
	Oocystis pusilla	OCPU	10	4.357488	1.694916	2353.044	4.71554		
	Dinobryon sertularia	DBST	1	4.357488	1.694916	518.5411	1.039165		
	Achnanthes minutissima	ACMN	1	2.178744	0.8474578	108.9372	0.218312		
	Gymnodinium sp.	GNXX	1	2.178744	0.8474578	5882.609	11.78885		

Slide #	Lake Sp name	Station Sp code	Date cells/col	Pplk Dens	Diversity % Dens	TSI-B Biovol	Tot Dens % Biovol	Tot Biovol	# spp
	Asterionella formosa	ASFO	1	2.178744	0.8474578	479.3237	0.9605729		
	Mallomonas sp.	MMXX	1	2.178744	0.8474578	827.9227	1.659171		
	Gloeocystis sp.	GLXX	16	2.178744	0.8474578	9063.575	18.16356		
EM74	Prospect Lake	PRO01	98-09-24	PPLK	0.8059378	27.8	711.5778	46427.95	5
	Cyclotella stelligera	CCST	1	601.3333	84.50704	33073.33	71.23583		
	Synedra rumpens	SNRM	1	80.17778	11.26761	11224.89	24.17701		
	Rhodomonas minuta	RDMN	1	20.04445	2.816902	400.8889	0.8634647		
	Chlamydomonas sp.	CHXX	1	5.011111	0.7042254	1628.611	3.507825		
	Unidentified flagellate	MXFG	1	5.011111	0.7042254	100.2222	0.2158662		
EM75	Razz Lake	RAZ01	98-09-23	PPLK	2.111837	29.4	286.9289	58095.28	12
	Oocystis pusilla	OCPU	5	135.6391	47.27272	36622.56	63.03879		
	Ankistrodesmus falcatus	AKFL	1.4	93.90399	32.72727	3286.64	5.657327		
	Sphaerocystis schroeteri	SFSR	5.6	13.04222	4.545454	2556.275	4.400143		
	Chromulina sp.	KMXX	1	10.43378	3.636363	208.6755	0.3591954		
	Oocystis lacustris	OCLA	2	7.825333	2.727273	4820.405	8.297413		
	Selenastrum minutum	SLMN	12.3	7.825333	2.727273	1925.032	3.313577		
	Dinobryon sertularia	DBST	2	5.216888	1.818182	1241.619	2.137212		
	Anacystis marina	ANMR	1	2.608444	0.9090908	782.5333	1.346983		
	Ulothrix sp.	ULXX	8	2.608444	0.9090908	1669.404	2.873563		
	Glenodinium sp.	GDXX	1	2.608444	0.9090908	1825.911	3.142959		
	Anabaena flos-aquae	ABFA	1	2.608444	0.9090908	2608.444	4.489942		
	Cosmarium sp.	CSXX	1	2.608444	0.9090908	547.7733	0.9428878		
EM76	Sunshine Lake	SUN01	98-09-24	PPLK	1.092688	25.8	299.6968	34540.79	9
	Rhodomonas minuta	RDMN	1	250.2323	83.49514	5004.645	14.48909		
	Dinobryon sertularia	DBST	5	17.45807	5.825243	10387.55	30.07329		
	Oocystis pusilla	OCPU	12	5.819355	1.941748	3770.942	10.91736		
	Unidentified flagellate	MXFG	1	5.819355	1.941748	116.3871	0.3369556		
	Ankistrodesmus falcatus	AKFL	1.5	5.819355	1.941748	218.2258	0.6317917		

Slide # 	Lake Sp name	Station Sp code	Date cells/col	Pplk Dens	Diversity % Dens	TSI-B Biovol	Tot Dens % Biovol	Tot Biovol	# spp
	Sphaerocystis schroeteri	SFSR	64	5.819355	1.941748	13035.36	37.73903		
	Anacystis marina	ANMR	1	2.909678	0.9708738	872.9033	2.527167		
	Cymbella minuta	CMMN	1	2.909678	0.9708738	1076.581	3.116839		
	Chromulina sp.	KMXX	1	2.909678	0.9708738	58.19355	0.1684778		

APPENDIX C

PLATE A

Taxa with a relative abundance of at least 5% in one depth interval.

1) *Achnanthes levanderi* Hustedt
   a) raphe valve
   a') araphe valve
1) *Achnanthes suchlandtii* Hustedt
   a) raphe valve
   a') araphe valve
2) *Aulacoseira distans (*Ehrenberg) Simonsen
   a) valve view
   b) valve view
   c) girdle view
   d) girdle view
3) *Cyclotella pseudostelligera* Hustedt
4) *Cyclotella stelligera* Cleve & Grunow
5) *Fragilaria brevistriata* Grunow
   a) valve view
   b) girdle view
   c) valve view
   d) girdle view
6) *Fragilaria construens var. venter* (Ehrenberg) Grunow
   a) valve view
   b) girdle view
7) *Fragilaria pinnata* Ehrenberg
   a) valve view
   b) girdle view
8) *Navicula schmassmannii* Hustedt
   a) valve view
   b) valve view
   c) girdle view

APPENDIX C (continued)

PLATE B
Taxa with a relative abundance of at least 1% in one depth interval.

9) *Achnanthes didyma* Hustedt
   a) raphe valve
   a') araphe valve
10) *Achnanthes exilis* Kützing
11) *Achnanthes helvetica* (Hustedt) Lange-Bertalot
   a) raphe valve
   a') araphe valve
12) *Achnanthes holstii* Cleve
   a) raphe valve
   a') araphe valve
13) *Achnanthes laterostrata* Hustedt
   a) raphe valve
   a') araphe valve
14) *Achnanthes minutissima (sensu lato)*
   a) valve view
   b) valve view
15) *Achnanthes nodosa* Cleve
   a) valve view
   b) valve view
16) *Achnanthes cf. rossii* Hustedt
17) *Achnanthes cf. saccula* Patrick
   a) raphe valve
   a') araphe valve
18) *Achnanthes cf. sphacelata* Carter
19) *Achnanthes cf. stewartii* Patrick
   a) raphe valve
   b) araphe valve
20) *Achnanthes subatomoides* (Hustedt) Lange-Bertalot & Archibald
   a) raphe valve
   b) araphe valve
   c) araphe valve

APPENDIX C (continued)

PLATE C
Taxa with a relative abundance of at least 1% in one depth interva.

21) *Amphora fogediana* Krammer
22) *Amphora inariensis* Krammer
23) *Anomoeneis cf. sphaerophora* (Brébisson) Grunow
24) *Asterionella formosa* Hassall
25) *Aulacoseira valida* (Grunow in Van Heurck) Krammer
26) *Caloneis lauta* Carter & Bailey-Watts
    a) valve view
    b) girdle view
27) *Cyclotella tripartita* Håkansson
28) *Cymbella cf. minuta* Hilse
29) *Cymbella minuta* Hilse
30) *Cymbella silesiaca* Bleisch
31) *Diploneis marginestriata* Hustedt
32) *Fragilaria capucina var. rumpens* (Kützing) Lange-Bertalot
33) *Fragilaria parasitica* (W. Smith) Grunow
34) *Gomphonema auritum* A. Braun ex. Kützing
35) *Gomphonema cf. micropus* Kützing
36) *Gomphonema parvulum var. parvulius* Lange-Bertalot & Reichardt

APPENDIX C (continued)

PLATE D
Taxa with a relative abundance of at least 1% in one depth interval (continued).

37) *Navicula cocconeiformis* Gregory ex. Greville
38) *Navicula cryptocephala* Kützing
39) *Navicula cryptotenella* Lange-Bertalot
40) *Navicula cf. digitulus* Husdtedt
41) *Navicula digitulus* Hustedt
42) *Navicula cf. festiva* Krasske
    a) valve 1
    b) valve 2
    c) valve
43) *Navicula globulifera* Hustedt
44) *Navicula laevissima* Kützing
45) *Navicula menisculus* Schumann
46) *Navicula pseudolanceolata var. denselineolata* Lange-Bertalot
47) *Navicula pupula* Kützing

APPENDIX C (continued)

PLATE E

Taxa with a relative abundance of at least 1% in one depth interval (continued).

48) *Nitzschia amphibia* Grunow
49) *Nitzschia bryophila* (Hustedt) Hustedt
50) *Nitzschia dissipata* (Kützing) Grunow
51) *Nitzschia cf. frustulum* (Kützing) Grunow in Cleve & Grunow
52) *Nitzschia recta* Hantzsch
53) *Nitzschia tubicola* Grunow
54) *Pinnularia infirma* Krammer
    a) valve view
    b) girdle view

APPENDIX C (continued)

PLATE – Charcoal
Some representative charcoal fragments.

* an example of a carbon spherule (fossil fuel charcoal)

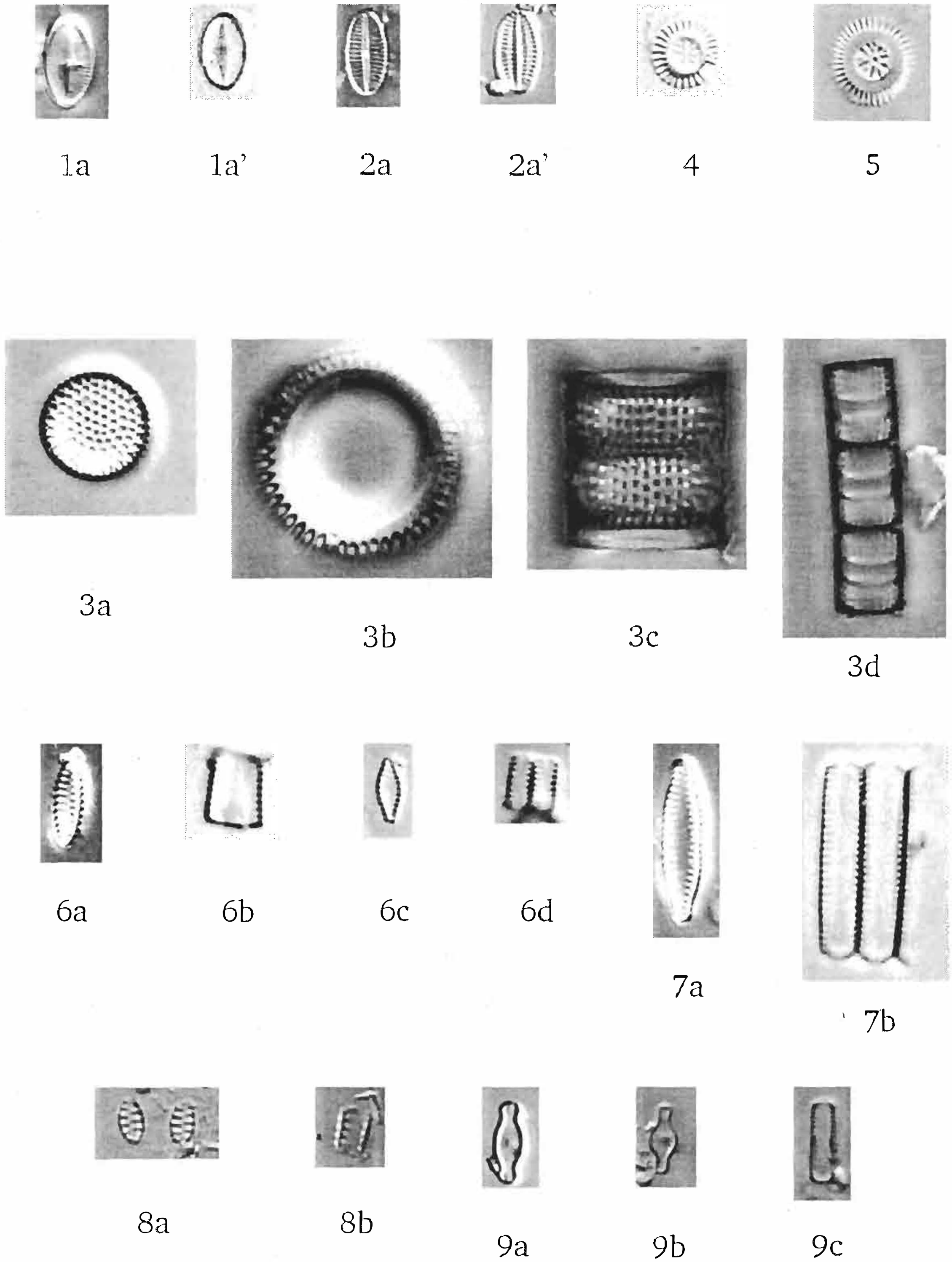


PLATE A

10 μm

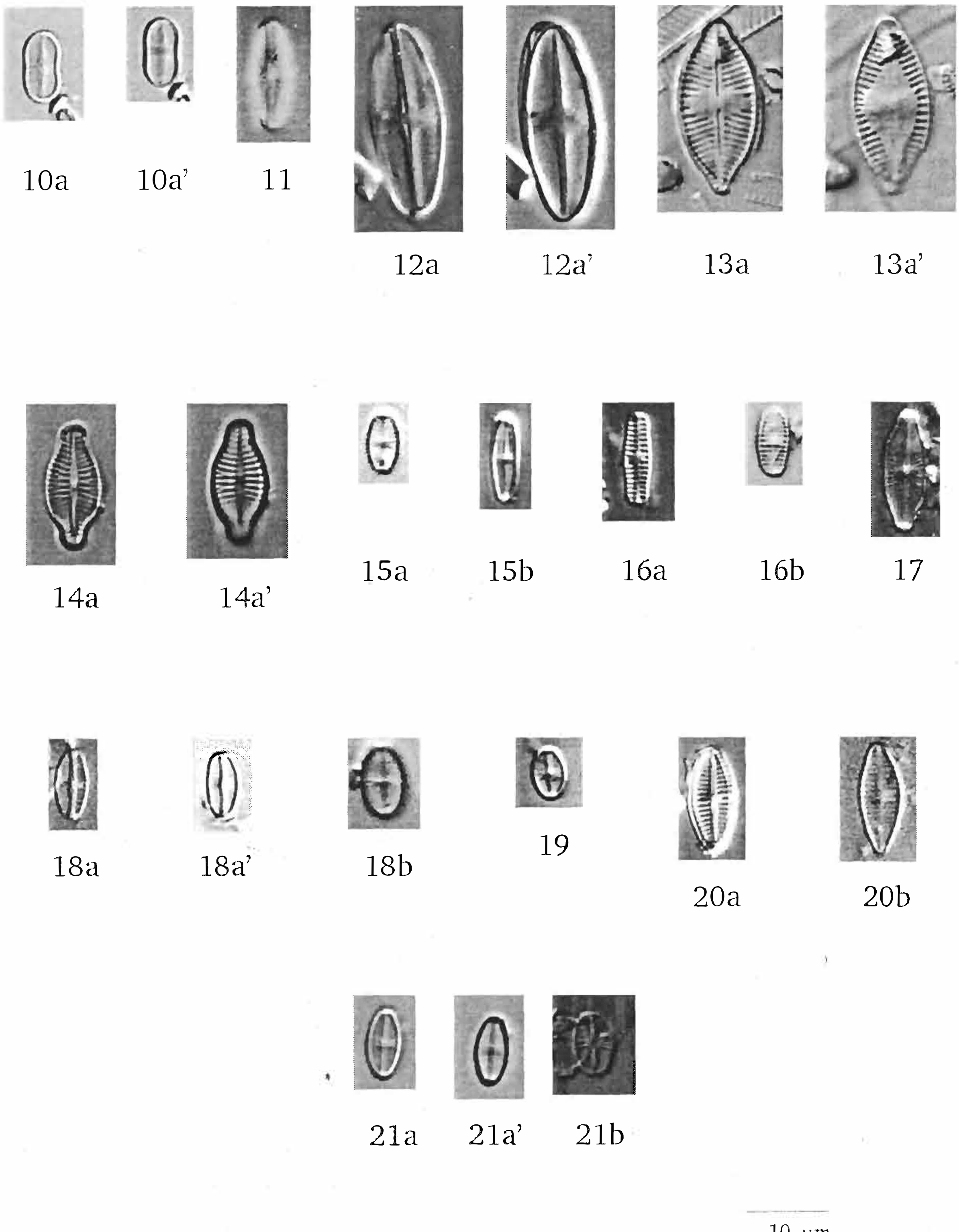

10a
10a'
11
12a
12a'
13a
13a'
14a
14a'
15a
15b
16a
16b
17
18a
18a'
18b
19
20a
20b
21a
21a'
21b
10 µm

PLATE B

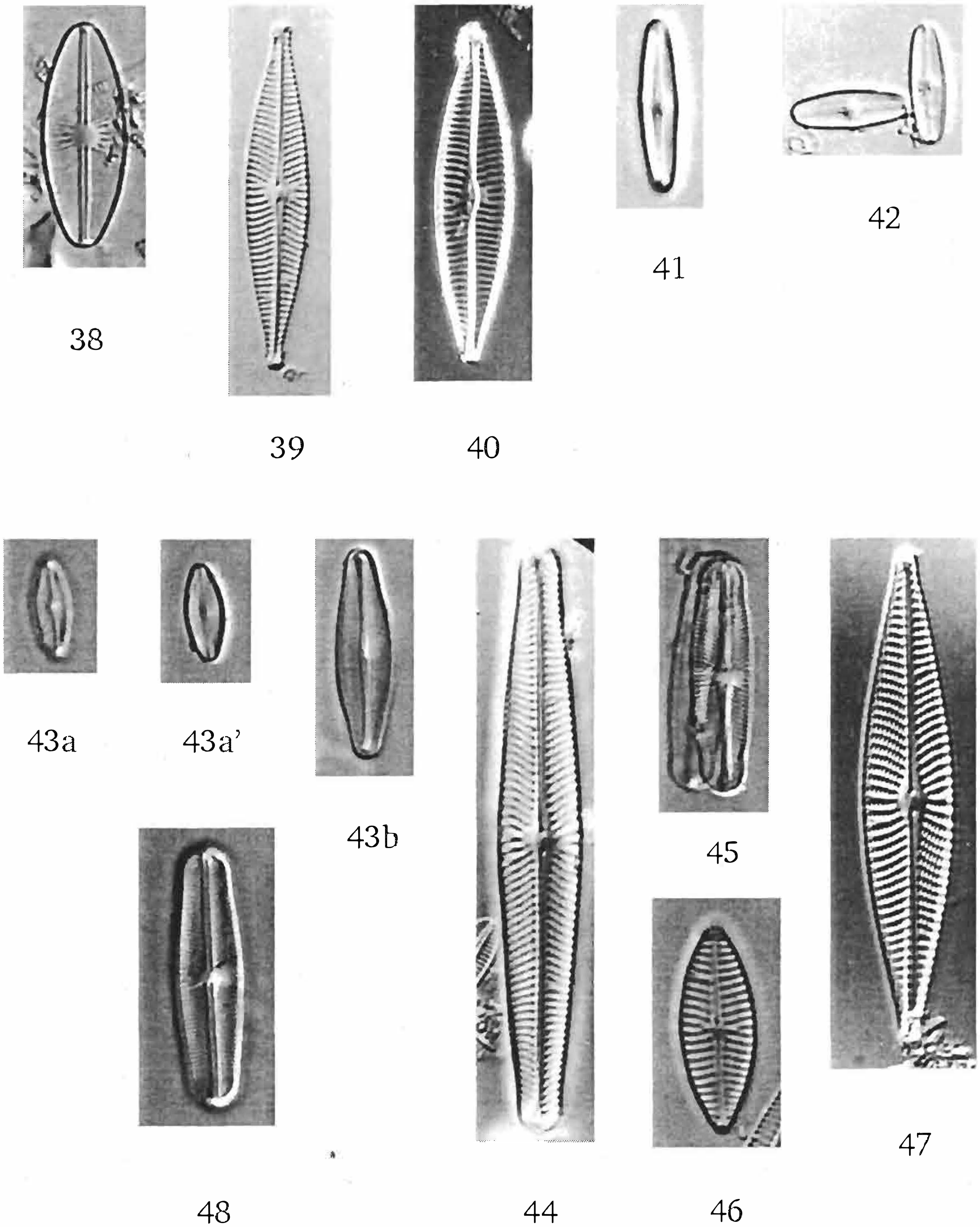
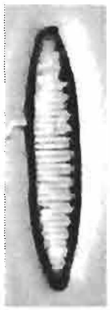
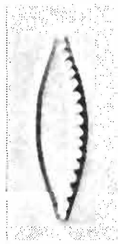


PLATE D

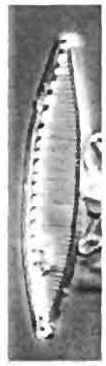


49

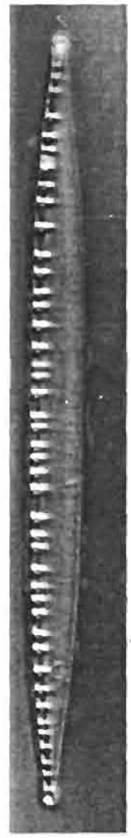


50

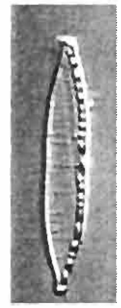
51



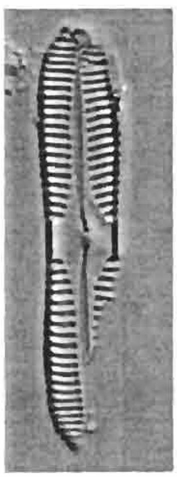
52



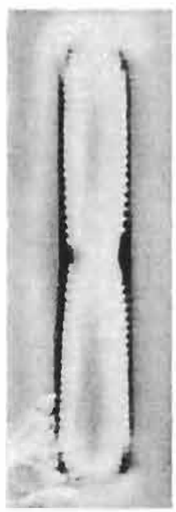
53



54



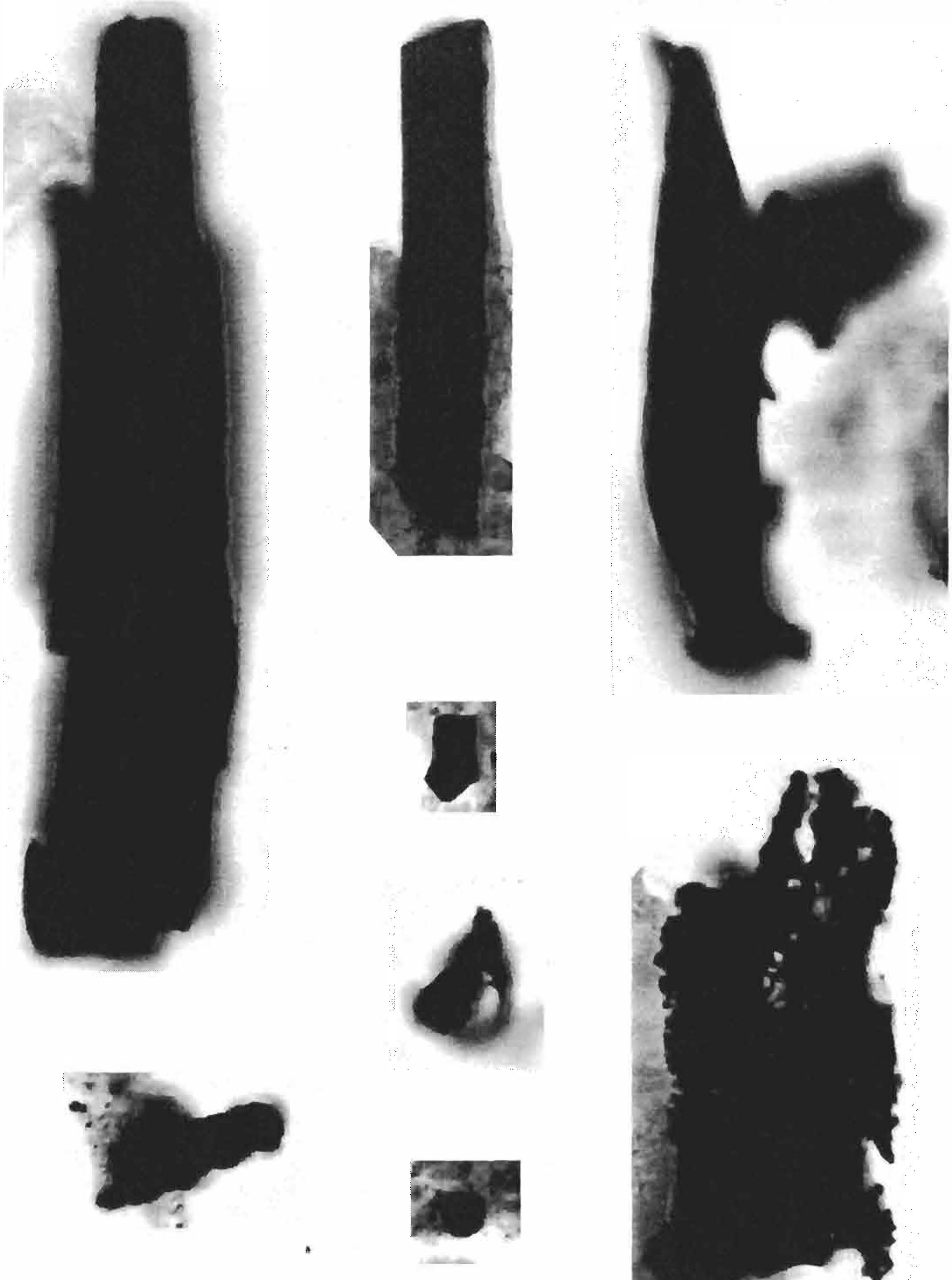
55a



55b

PLATE E

10 μm



*

PLATE - CHARCOAL

10 μm

APPENDIX D

Diatom Relative Abundances

Depth (cm)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	28-29
Achnanthes levanderi	6.4	1.8	2.3	2.7	1.2	2.0	0.2	1.2	2.7	1.2	0.0	0.0	1.0	0.5	0.7	0.5	0.5	1.0	0.0	1.2	2.2	1.5	2.5	0.5	0.2	1.2	0.7	1.0	0.5
Achnanthes suchlandtii	2.3	3.3	4.3	6.2	6.3	9.9	8.7	8.7	11.1	7.4	8.7	5.4	7.7	7.8	8.3	8.6	7.3	8.3	9.7	7.7	8.8	7.6	4.4	6.4	10.8	10.7	13.3	8.5	15.3
Aulacoseira distans	5.4	3.3	5.3	6.4	4.9	6.2	5.5	7.0	3.7	10.9	7.2	8.8	5.0	9.3	7.1	10.8	9.7	8.3	9.7	8.2	4.9	9.8	7.8	10.0	9.6	6.6	15.9	9.2	7.4
Cyclotella pseudostelligera	0.6	2.5	3.3	2.5	5.1	8.1	11.1	8.3	3.4	6.2	6.0	6.6	4.5	11.2	6.1	9.9	7.0	6.1	3.3	1.5	1.2	1.7	3.4	0.7	5.3	2.7	3.1	3.2	2.2
Cyclotella stelligera	0.6	0.8	1.8	1.7	0.7	2.2	8.0	12.6	14.3	6.5	9.9	7.6	11.7	16.1	11.0	11.1	4.8	4.6	2.1	4.5	2.7	3.4	2.9	1.0	4.1	3.6	5.1	4.6	2.7
Fragilaria brevistriata	17.4	17.5	17.3	18.0	17.7	6.4	10.6	11.2	9.8	13.6	9.9	8.1	11.9	11.0	15.2	12.3	17.9	20.6	20.0	27.2	25.7	22.6	25.7	24.6	19.2	23.3	20.2	25.0	20.5
Fragilaria construens var. venter	15.6	16.5	3.8	8.9	10.9	9.9	3.6	5.3	3.9	5.0	1.2	7.6	6.2	3.7	2.0	3.0	4.6	4.4	6.4	4.0	6.8	2.7	9.8	3.8	3.8	2.9	2.2	1.2	1.7
Fragilaria pinnata	18.3	17.3	25.5	21.5	28.9	20.0	14.2	14.8	23.6	20.8	21.6	18.9	19.4	8.8	18.4	14.0	20.3	21.1	20.4	21.3	21.8	19.2	16.4	27.2	21.2	22.3	15.9	24.5	17.6
Navicula schmassmannii	5.6	4.0	3.3	2.7	2.2	5.7	2.9	3.4	5.9	3.5	2.5	7.8	8.0	5.9	4.7	3.0	0.7	3.4	4.8	3.2	6.6	4.4	5.6	4.3	2.2	5.6	2.9	2.7	5.2
Achnanthes didyma	1.2	1.0	1.3	1.0	1.5	0.2	1.4	1.5	1.7	0.0	3.2	1.7	1.0	0.0	1.5	2.0	0.0	0.2	1.2	0.5	1.7	1.7	0.0	1.2	0.0	0.2	0.7	0.5	1.0
Achnanthes exilis	0.0	0.0	0.0	0.2	0.0	1.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Achnanthes helvetica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2	0.2	0.0	1.2	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.2	0.0	0.2
Achnanthes holstii	0.0	0.0	0.3	0.0	0.0	0.5	1.2	1.0	0.5	0.7	1.5	3.4	1.7	1.0	0.5	0.5	0.0	0.2	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.7	0.7	0.2	0.0
Achnanthes laterostrata	1.4	2.0	2.0	1.2	0.5	3.2	3.6	1.7	2.7	2.0	2.2	1.2	2.2	2.7	2.0	2.7	3.4	1.9	3.6	4.0	1.7	3.9	1.7	2.6	3.1	1.2	1.0	3.4	3.5
Achnanthes minutissima	1.7	1.5	1.5	1.2	1.5	0.2	2.7	1.2	2.5	2.2	0.0	0.5	2.0	0.7	2.2	0.2	2.7	0.2	1.0	0.5	0.0	0.0	1.0	0.0	0.5	0.5	0.0	0.0	1.2
Achnanthes nodosa	0.0	0.5	0.0	0.0	0.5	0.5	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.5	1.0	0.2	0.0	0.0	0.0	1.0	0.7	0.5	0.5	0.5	0.2	0.0
Achnanthes cf. rossii	0.6	0.0	0.0	1.5	0.5	1.0	0.5	0.5	0.0	0.0	0.5	0.5	0.0	0.7	1.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.5	0.2	0.5	0.0	0.5	0.2
Achnanthes cf. saccula	0.4	1.5	0.5	1.0	0.2	1.5	1.7	0.2	0.2	3.0	1.0	0.2	0.2	0.5	1.0	1.0	1.5	0.5	0.5	0.5	0.5	0.2	1.7	0.2	0.5	0.2	0.5	0.5	1.5
Achnanthes cf. sphacelata	0.2	2.0	1.0	1.5	0.7	1.7	1.7	1.2	0.2	0.7	0.0	0.7	2.0	0.7	0.7	0.5	0.5	1.0	1.0	0.2	0.0	0.2	0.5	1.4	1.7	0.0	0.0	0.0	2.0
Achnanthes cf. stewartii	0.4	0.8	0.5	0.5	0.2	0.5	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.2	1.5	1.0	0.2	0.0	1.2	1.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Achnanthes subatomoides	0.4	0.8	1.5	0.5	0.2	0.5	0.2	2.2	2.0	0.7	2.7	2.0	0.2	0.7	3.4	3.2	2.7	2.7	1.7	2.0	2.9	2.2	1.5	0.5	1.4	0.7	1.0	1.2	1.5
Amphora fogediana	*0.2	0.0	0.0	0.0	0.5	0.5	0.0	1.0	1.5	1.2	0.2	0.2	0.2	0.5	0.2	0.7	0.7	0.5	0.7	0.2	0.5	0.0	0.0	1.0	0.2	0.2	0.5	0.0	0.0
Amphora inariensis	0.4	1.0	1.3	0.5	0.7	0.5	1.7	1.0	0.7	0.2	0.7	0.7	0.7	1.0	0.5	1.2	0.5	0.7	1.2	0.5	0.2	0.2	0.7	1.0	0.7	0.2	2.2	0.0	1.5
Anomoeneis cf. sphaerophora	0.0	0.5	0.3	0.7	0.7	0.7	2.4	1.0	1.7	1.2	0.7	1.2	0.5	0.7	0.5	1.2	0.7	1.7	1.7	0.2	0.2	0.7	0.5	0.2	2.2	1.5	0.7	1.5	0.2
Asterionella formosa	0.0	0.0	2.5	1.0	0.5	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aulacoseira valida	0.6	0.0	0.0	0.0	0.0	0.2	0.0	0.5	0.5	0.0	0.5	0.5	0.2	0.0	0.5	0.2	0.0	0.0	0.2	0.5	0.0	0.0	0.0	1.0	0.0	0.0	0.5	0.0	0.0
Caloneis lauta	0.0	0.5	0.0	0.5	0.0	0.0	0.2	0.2	0.2	0.5	0.2	0.0	1.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Cyclotella tripartita	1.4	1.0	0.5	0.2	0.0	0.0	0.2	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.5	0.2	0.5	0.5	0.0	0.5	1.5	0.5	0.0	1.2
Cymbella cf. minuta	1.0	0.0	0.3	0.2	0.0	0.0	1.7	0.0	0.5	0.2	0.7	0.5	0.0	0.0	0.5	0.0	0.2	0.2	0.5	0.5	0.0	0.0	0.2	0.0	1.7	0.7	0.0	0.2	0.5
Cymbella minuta	0.0	1.3	0.8	0.0	0.5	1.0	1.4	0.5	0.7	0.5	0.5	0.5	0.5	0.0	1.5	2.0	0.2	0.5	0.2	1.2	0.2	0.5	1.0	0.0	0.2	0.0	0.5	1.2	0.5
Cymbella silesiaca	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.2	0.0	1.5	0.2	0.0	0.0	0.7	0.2	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.2
Diploneis marginestriata	0.0	0.0	0.0	1.0	0.5	0.2	0.5	0.2	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.2	0.5	0.0	0.0	0.0	0.0	0.0
Fragilaria capucina var. rumpens	1.4	0.0	0.8	0.7	0.0	0.2	0.0	0.0	0.7	0.7	0.2	1.0	0.5	1.5	0.7	0.2	1.9	3.4	1.9	1.2	1.2	2.0	1.7	1.9	1.2	2.2	1.0	0.5	1.0
Fragilaria parasitica	0.0	0.5	0.5	0.7	0.2	0.2	0.0	0.2	0.5	0.0	0.0	0.0	0.0	0.5	0.0	0.0	1.2	1.0	0.5	0.2	2.9	0.7	0.0	1.0	0.2	1.2	0.0	0.7	0.0
Gomphonema auritum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gomphonema cf. micropus	0.0	0.0	0.0	0.0	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gomphonema parvulum var. parvulius	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Navicula cocconeiformis	0.2	0.8	0.0	0.5	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.5	0.2	0.0	0.5	0.5	0.2	0.0	0.0	0.7	0.0	0.7	0.0	0.2	0.7	1.0	0.2
Navicula cryptocephala	0.0	0.0	0.0	0.0	0.7	0.0	0.0	1.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
Navicula cryptotenella	0.4	0.0	0.0	0.0	0.0	0.5	0.0	0.2	0.0	0.0	0.0	0.5	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.5	0.0	0.0	0.0	0.2
Navicula cf. digitulus	0.0	0.3	0.0	0.0	0.5	0.0	0.0	1.5	0.5	1.5	1.5	1.5	0.2	0.2	0.2	0.0	0.7	0.5	0.0	0.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.0
Navicula digitulus	1.0	0.0	0.0	0.5	0.7	0.0	0.5	0.5	0.0	0.5	4.2	2.0	1.7	1.0	1.0	1.7	0.5	0.7	0.7	0.5	0.0	0.5	2.2	0.2	1.4	0.5	0.2	1.0	1.7
Navicula cf. festiva	1.0	1.0	2.8	2.0	2.7	1.0	2.4	1.7	0.0	1.0	1.2	1.5	3.0	2.2	1.2	0.2	0.7	0.2	0.7	0.0	0.0	0.5	0.5	0.7	0.5	0.5	0.7	0.0	0.2
Navicula globulifera	1.4	3.0	0.8	2.5	0.0	2.0	0.2	1.2	1.7	0.7	1.0	0.5	1.0	1.0	0.5	0.7	0.2	0.2	0.5	0.7	0.2	1.0	0.2	0.5	1.2	1.2	0.7	0.7	0.7
Navicula laevissima	0.0	1.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Navicula menisculus	0.4	0.0	1.3	0.0	0.0	0.2	0.5	0.5	0.2	0.2	1.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.2	0.7	0.7	1.7	1.0	1.0	0.2	0.7	0.0	0.2
Navicula pseudolanceolata var. denselineoli	0.2	0.3	0.8	0.0	0.0	1.0	0.7	0.5	0.0	0.0	1.0	0.2	0.0	0.7	0.0	1.5	0.5	0.0	0.0	0.5	1.0	1.2	0.2	0.2	0.2	0.7	0.5	0.5	2.0
Navicula pupula	0.0	1.0	1.5	0.5	0.2	0.0	0.2	0.0	0.0	0.0	1.5	1.0	0.5	0.5	0.2	2.0	0.5	1.2	0.5	0.7	0.2	0.7	0.0	0.2	0.0	0.2	0.2	0.0	0.5
Nitzschia amphibia	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.5	0.7	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Nitzschia bryophila	0.8	1.0	1.3	0.5	0.0	0.2	0.5	0.5	0.2	0.0	0.0	0.2	0.0	1.0	0.5	0.7	1.5	0.5	0.0	0.2	0.0	0.0	1.0	1.0	1.2	0.0	1.0	0.2	0.0
Nitzschia dissipata	0.0	0.0	0.0	0.5	1.0	0.2	0.5	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia cf. frustulum	1.5	0.8	0.8	1.0	0.0	1.2	0.0	0.0	0.0	0.0	0.2	0.0	0.5	0.0	0.0	0.2	0.5	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.5	0.0	0.5	0.2
Nitzschia recta	0.2	0.0	0.5	0.5	0.2	1.2	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.2	0.2	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0
Nitzschia tubicola	0.4	1.0	0.0	0.5	0.5	0.5	0.2	0.0	0.0	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinnularia infirma	1.0	0.0	0.0	0.0	0.0	0.5	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	1.2	0.0	0.2	0.2	0.0	0.0
TOTAL VALVE COUNT	**518**	**398**	**393**	**405**	**412**	**404**	**415**	**403**	**407**	**403**	**403**	**408**	**403**	**410**	**417**	**406**	**413**	**412**	**421**	**404**	**409**	**407**	**408**	**419**	**426**	**413**	**415**	**412**	**404**

APPENDIX E
ANALOG analysis

Stratigraphic plot of minimum dissimilarity coefficients (DCs) for squared chi-squared distance

Sample ...	min DC	.0000 .1700 .3400 .5100 .6800 .8500 1.0200
ML-A-1	.4864	
ML-A-2	.4637	
ML-A-3	.6697	
ML-A-4	.6072	
ML-A-5	.5327	
ML-A-6	.7268	
ML-A-7	.7674	
ML-A-8	.7488	
ML-A-9	.6553	
ML-A-10	.7060	
ML-A-11	.6514	
ML-A-12	.7572	
ML-A-13	.6229	
ML-A-14	.8491	
ML-A-15	.6397	
ML-A-16	.7961	
ML-A-17	.7223	
ML-A-18	.6820	
ML-A-19	.7309	
ML-A-20	.5830	
ML-A-21	.6203	
ML-A-22	.6442	
ML-A-23	.6277	
ML-A-24	.6114	
ML-A-25	.6749	
ML-A-26	.6006	
ML-A-27	.7341	
ML-A-28	.5513	
ML-A-29	.7076	
		.0000 .1700 .3400 .5100 .6800 .8500 1.0200

Percentiles and histogram for squared chi-squared distance

Percentiles for comparisons between modern samples - based on 861 DCs:

Percentile	Bounding DCs... (****** = outside extreme observed DCs)	
1.0%	.1539 to	.1667
2.5%	.4686 to	.4752
5.0%	.6667 to	.6667
10.0%	.8889 to	.8889
25.0%	1.3333 to	1.3333
50.0%	2.0000 to	2.0000
75.0%	2.0000 to	2.0000

Range of DCs is .0157 to 2.0000

APPENDIX F
WACALIB Reconstruction Data

Depth (cm)	lgConductivity (µS/cm)	*Conductivity (µS/cm)	pH	lgTP (µg/L)	*TP (µg/L)
0-1	1.542	34.8	7.4	1.265	18.4
1-2	1.599	39.7	7.5	1.228	16.9
2-3	1.587	38.6	7.5	1.206	16.1
3-4	1.555	35.9	7.5	1.173	14.9
4-5	1.601	39.9	7.6	1.236	17.2
5-6	1.445	27.9	7.4	1.042	11.0
6-7	1.411	25.8	7.3	0.8374	6.9
7-8	1.375	23.7	7.2	0.8479	7.0
8-9	1.412	25.8	7.3	0.9110	8.1
9-10	1.435	27.2	7.3	1.002	10.0
10-11	1.419	26.2	7.3	0.9219	8.4
11-12	1.428	26.8	7.3	1.030	10.7
12-13	1.456	28.6	7.3	0.9763	9.5
13-14	1.329	21.3	7.1	0.7378	5.5
14-15	1.415	26.0	7.2	0.8710	7.4
15-16	1.344	22.1	7.1	0.8079	6.4
16-17	1.473	29.7	7.3	0.9630	9.2
17-18	1.504	31.9	7.4	0.9982	10.0
18-19	1.509	32.3	7.4	1.033	10.8
19-20	1.539	34.6	7.4	1.044	11.1
20-21	1.570	37.2	7.5	1.082	12.1
21-22	1.496	31.3	7.4	1.019	10.4
22-23	1.545	35.1	7.4	1.102	12.6
23-24	1.593	39.2	7.5	1.190	15.5
24-25	1.483	30.4	7.4	0.9825	9.6
25-26	1.546	35.2	7.5	1.018	10.4
26-27	1.386	24.3	7.2	0.8754	7.5
27-28	1.528	33.7	7.4	1.046	11.1
28-29	1.469	29.4	7.4	0.8670	7.4

*Data have been back-transformed.

APPENDIX G

Planktonic:Benthic ratio of diatoms

Depth (cm)	Planktonic(+T)	Benthic	Planktonic	Benthic(+T)
1	25.5	74.5	8.5	91.5
2	24.1	75.9	7.5	92.5
3	17.8	82.3	13.3	86.8
4	21.5	78.5	11.9	88.1
5	22.1	77.9	11.2	88.8
6	27.2	72.8	17.0	83.0
7	28.4	71.6	24.8	75.2
8	34.0	66.0	28.6	71.4
9	26.5	73.5	21.9	78.1
10	29.8	70.2	24.1	75.9
11	25.1	74.9	23.6	76.4
12	32.1	67.9	23.5	76.5
13	28.1	71.9	21.4	78.6
14	41.7	58.3	36.6	63.4
15	27.5	72.5	24.8	75.2
16	35.2	64.8	32.0	68.0
17	28.1	71.9	21.5	78.5
18	26.9	73.1	19.2	80.8
19	24.0	76.0	15.7	84.3
20	20.3	79.7	15.1	84.9
21	17.1	82.9	9.0	91.0
22	20.1	79.9	15.5	84.5
23	26.2	73.8	14.7	85.3
24	18.4	81.6	12.6	87.4
25	24.5	75.5	19.5	80.5
26	19.4	80.6	14.3	85.7
27	28.2	71.8	25.1	74.9
28	18.7	81.3	17.0	83.0
29	16.3	83.7	13.6	86.4

+T - including the tychoplanktonic taxa